PB-250 114

REGIONAL AIR POLLUTION STUDY (RAPS) EMISSION INVENTORY HANDBOOK. VOLUME 3

Rockwell International

Prepared for:

Environmental Sciences Research

February 1976

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EPA-600/3-76-011c
February 1976

RAPS EMISSION INVENTORY HANDBOOK

Volume 3

[Task Order 37]

by

Rockwell International Corporation
Air Monitoring Center
Newbury Park, North Carolina 91320

Contract No. 68-02-1081

Project Officer

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OFFICE OF RESEARCH AND DEVELOPMENT
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RESEARCH TRIANGLE PARK, NORTH CAROLINA 27711

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392

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA-600/3-76-011c

2.

3. RECIPIENT'S ACCESSION NO.

4. TITLE AND SUBTITLE
RAPS EMISSION INVENTORY HANDBOOK
Volume 3

5. REPORT DATE
February 1976

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
Rockwell International Corporation
Air Monitoring Center

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Rockwell International Air Monitoring Center
2421A Hillcrest Drive
Newbury Park, CA 91320

10. PROGRAM ELEMENT NO.
AAA003 26AAI/413

11. CONTRACT/GRANT NO.
68-02-1081
[Task Order 37]

12. SPONSORING AGENCY NAME AND ADDRESS
Office of Research and Development
Environmental Sciences Research Laboratory
Research Triangle Park, N.C.

13. TYPE OF REPORT AND PERIOD COVERED
Final

14. SPONSORING AGENCY CODE
EPA-ORD

15. SUPPLEMENTARY NOTES
See also Volume 1, EPA-600/3-76-011a, and Volume 2, EPA-600/3-76-011b

16. ABSTRACT

The Regional Air Pollution Study (RAPS), which encompasses the St. Louis Air Quality Control Region, is the largest and most comprehensive attempt to date to obtain a quantitative understanding of urban air pollution. Its aim is to describe the complex relationships between emissions to the atmosphere, atmospheric dispersions and transformation processes, and ambient concentrations of pollutants. In addition, numerous corollary studies are planned under the RAPS "umbrella."

An accurate, detailed and comprehensive inventory of emission to the atmosphere constitutes a basic input to this understanding. The RAPS emission inventory was planned to provide far more detailed information than has been available anywhere in the past; its aim is to obtain hourly data for key pollutants based insofar as possible on measured values. Thus, emission data should be available for a base period of a year, commensurate in detail and accuracy with data on ambient concentrations and micrometeorological information gathered by the Regional Air Monitoring Stations.

The ultimate value of the RAPS Study will, it is hoped, not be confined to the St. Louis area, but rather will provide a model for future studies of this type in other areas. For this reason the National Air Data Branch provided complete documentation of all efforts connected with the assembly of the regional emission inventory so that the techniques and methodology developed for this project will be applicable to future studies.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
*Air Pollution *Emission *Data	St. Louis, Mo	13B 14G

PRICES SUBJECT TO CHANGE

18. DISTRIBUTION STATEMENT RELEASE UNLIMITED	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES 392
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE $10.75 - 2.25

EPA Form 2220-1 (9-73)

DISCLAIMER

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RAPS Emission Inventory Handbook

TABLE OF CONTENTS

Volume 1 - A. Introduction

- Purpose and Content of Handbook

B. An Overview of the Regional Air Pollution Study

- RAPS Prospectus
- RAPS Series I Study Plan
- RAPS Experimental Design Plan
- Budget Summary

C. The RAPS Emission Inventory

- Purpose of Inventory
- RAPS Participants
- RAPS Inventory Users and Uses
- Special Emission Inventories for Field Studies
- Presentation of NEDS Emission Data

D. Scope of the Inventory

- Pollutants of Importance to RAPS
- Weighted Sensitivity Analysis Program
- Precision Analysis
- Emissions Projections

Volume 2 - E. Classification of Sources

F. Point Sources

- Survey of Existing Emission Inventory Data
- Point Source Methodology
- Hydrocarbon Inventory Methodology
- Heat Emission Methodology
- Emission Factor Development

G. Area Sources

- Preliminary Information
- Gridding Study
- Stationary Area Source Methodology
- Highway Area Source Methodology
- River Vessel Methodology and Inventory
- Fugitive Dust Methodology
- Airport Emission Methodology and Inventory
- Off-highway Mobile Sources Methodology

Volume 3 - H. Line Sources

Highway (Line Source) Methodology
Railroad Methodology and Inventory

I. Emission Models

J. Validation of Area and Line Emission Models

Validation Methodology
Field Measurements

K. RAPS Emission Inventory Data Handling System

Purpose and Scope
Hardware System
Software Development

L. Information Transfer

Line Sources

Early in the RAPS program the National Air Data Branch recognized that defining emission sources as either point or area as in the NEDS system was not sufficiently accurate for the RAPS program. Thus, line sources were added to point and area sources. This category contains primarily automotive and railroad emissions. River vessel emissions were also examined; it was determined that their emissions were not sufficient for line sources definition. The two methodologies presented in this section are highway (1) and railroad (2) line sources.

1. Methodology for the Determination of Emission Line Sources, Washington University, April 1975

2. Rail Operations Air Pollution Emission Study Plan for St. Louis, Department of Transportation, preliminary draft

METHODOLOGY FOR THE DETERMINATION OF EMISSION LINE SOURCES

Environmental Protection Agency
Contract No. 68-02-1417
February 28, 1975

Washington University
School of Engineering and Applied Science
Department of Civil Engineering
St. Louis, Missouri 63130

Dr. Lonnie E. Haefner
Principal Investigator

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TABLE OF CONTENTS

Page

CHAPTER I - INTRODUCTION - STUDY DESIGN - - - - - - - - - - - - - - - - 1

- A.) Introduction - Objectives of Research - - - - - - - - - - 1
- B.) Limited Literature Search - - - - - - - - - - - - - - - - - - 2
  - 1.) Relevance of Air Standards - - - - - - - - - - - - - 2
  - 2.) Relationships of Emissions to Key Traffic Engineering Stimuli - - - - - - - - 3
- C.) Formal Research Plan - 12
  - 1.) Emissions Related Traffic Flow Research Aspects - 12
  - 2.) Specific Work Plan of Research - - - - - - - - - - 15

CHAPTER II - DATA DEVELOPMENT - 22

CHAPTER III - MODEL DEVELOPMENT - 27

- A.) Overview of Model Logic - - - - - - - - - - - - - - - - - - 27
- B.) Software System Development - - - - - - - - - - - - - - - - 33

CHAPTER IV - DOCUMENTATION OF EMISSION LINE SOURCES - - - - - - - - 40

- A.) Introduction - Issues in Defining Line Sources - - - - 40
- B.) Basic Definitions - Delineation of Gross Line Sources - 40
- C.) Refined Level - Ultimate Definition of Line Sources - - 49
- D.) Synthesis of Line Source Information- - - - - - - - - - 63
- E.) Related Processing Costs - - - - - - - - - - - - - - - - - 75
- F.) Limited Sensitivity Analysis - - - - - - - - - - - - - - - 76

CHAPTER V - CONCLUSION - 87

- A.) Use and Applicability of Present Research and Modelling Results - - - - - - - - - - - - - - - - - - 87
- B.) Recommendations for Further Research - - - - - - - - - - 88
- C.) Closing Comments on Status of Line Source-Traffic Attribute Modelling - - - - - - - - - - - - 91

(Continued)

TABLE OF CONTENTS (Continued)

Page

BIBLIOGRAPHY - 93

Selected Research Bibliography - - - - - - - - - - - - - - - - 94

St. Louis Area Traffic Data Sources - - - - - - - - - - - - - - 95

Professional Interviews - 96

APPENDIX A - COMPUTER PROGRAM DOCUMENTATION - - - - - - - - - - - - 97

A-1 NETSEN Program - 98

A-2 HRCVRT Program - 123

A-3 Data Management Program - - - - - - - - - - - - - - - - - - - 133

A-4 Interface Program - 137

APPENDIX B - EXAMPLES OF DATA COLLECTION AND CODING FORMAT - - - - 143

LIST OF TABLES

Page

TABLE 1 - ADT RANGES USED FOR GROSS LEVEL LINE SOURCE DEFINITION - - - - - - - - - - - - - - - - - - 42

TABLE 2 - GROSS LEVEL LINE SOURCE EMISSIONS (FUNCTIONAL CLASS-FREEWAYS) - - - - - - - - - - - - 44

TABLE 3 - GROSS LEVEL LINE SOURCE EMISSIONS (FUNCTIONAL CLASS-PRINCIPAL ARTERIALS) - - - - 46

TABLE 4 - GROSS LEVEL LINE SOURCE EMISSIONS (FUNCTIONAL CLASS-MINOR ARTERIALS) - - - - - - 48

TABLE 5 - ADT RANGES USED FOR ULTIMATE LINE SOURCE DEFINITION - - 51

TABLE 6 - ULTIMATE LINE SOURCE EMISSIONS (FUNCTIONAL CLASS-FREEWAYS) - - - - - - - - - - - - 53

TABLE 7 - ULTIMATE LINE SOURCE EMISSIONS (FUNCTIONAL CLASS-FREEWAYS) - - - - - - - - - - - - 55

TABLE 8 - ULTIMATE LINE SOURCE EMISSIONS (FUNCTIONAL CLASS-FREEWAYS) - - - - - - - - - - - - 57

TABLE 9 - ULTIMATE LINE SOURCE EMISSIONS (FUNCTIONAL CLASS-FREEWAYS) - - - - - - - - - - - - 59

TABLE 10 - ULTIMATE LINE SOURCE EMISSIONS (FUNCTIONAL CLASS-PRINCIPAL ARTERIALS) - - - - 61

TABLE 11 - ULTIMATE LINE SOURCE EMISSIONS (FUNCTIONAL CLASS-PRINCIPAL ARTERIALS) - - - - 64

TABLE 12 - ULTIMATE LINE SOURCE EMISSIONS (FUNCTIONAL CLASS-PRINCIPAL ARTERIALS) - - - - 66

TABLE 13 - ULTIMATE LINE SOURCE EMISSIONS (FUNCTIONAL CLASS-PRINCIPAL ARTERIALS) - - - - 68

TABLE 14 - ULTIMATE LINE SOURCE EMISSIONS (FUNCTIONAL CLASS-MINOR ARTERIALS) - - - - - - 70

TABLE 15 - ULTIMATE LINE SOURCE EMISSIONS (FUNCTIONAL CLASS-MINOR ARTERIALS) - - - - - - 72

TABLE 16 - ULTIMATE LINE SOURCE EMISSIONS (FUNCTIONAL CLASS-MINOR ARTERIALS) - - - - - - 74

(Continued)

LIST OF TABLES (Continued)

Page

TABLE 17 - SUMMARY OF ULTIMATE LINE SOURCE EMISSIONS INFORMATION - 76

TABLE 18 - PERCENTAGE OF TOTAL EMISSIONS CONTRIBUTED BY FUNCTIONAL CLASS OF LINE SOURCE - - - - - - - - - 77

TABLE 19 - COST SUMMARY FOR TYPICAL SOFTWARE SYSTEM RUN - - - - - 79

TABLE 20 - EMISSIONS SUMMARY FOR FREEWAY CORRIDOR DIVERSION - - - 82

TABLE 21 - EMISSIONS SUMMARY FOR PARALLEL ARTERIAL DIVERSION - - - 85

LIST OF FIGURES

Page

FIGURE 1. Speed Correction Factors for 1968 Model Year Vehicles in Low Altitudes - - - - - - - - - - - - 4

FIGURE 2. Speed Correction Factors for 1968 Model Year Vehicles in Denver- - - - - - - - - - - - - - - - - 5

FIGURE 3. Speed Correction Factors for 1971 Model Year Vehicles in Denver- - - - - - - - - - - - - - - - - 6

FIGURE 4. Pollution Levels Along Transverse Street Cross Section of Centered Expressway with Joint Development Structures - - - - - - - - - - - - - 8

FIGURE 5. Pollution Levels Along Transverse Street Cross Section of Centered Expressway without Joint Development Structures - - - - - - - - - - - - - 9

FIGURE 6. Pollution Levels Along Transverse Street Cross Section of Centered Expressway-Boulevard - - - - - - - - 10

FIGURE 7. Comparison of City Street and Freeway Conditions - - - 11

FIGURE 8. Flow Parameters Related to Emissions and/or Air Quality Phenomena - - - - - - - - - - - - - - - 16

FIGURE 9. Research Work Plan - 17

FIGURE 10. Master Logic of NETSEN Model - - - - - - - - - - - - - - - 28

FIGURE 11. Traffic Emissions Software System - - - - - - - - - - - 34

FIGURE 12. Gross Level Line Sources (Functional Class-Freeways) - 43

FIGURE 13. Gross Level Line Sources (Functional Class-Principal Arterials) - - - - - - - - - - - - - - - 45

FIGURE 14. Gross Level Line Sources (Functional Class-Minor Arterials) - - - - - - - - - - - - - - - - - 47

FIGURE 15. Ultimate Line Sources (Functional Class-Freeways) - - 52

FIGURE 16. Ultimate Line Sources (Functional Class-Freeways) - - 54

FIGURE 17. Ultimate Line Sources (Functional Class-Freeways) - - 56

FIGURE 18. Ultimate Line Sources (Functional Class-Freeways) - - 58

(Continued)

LIST OF FIGURES (Continued)

Page

FIGURE 19. Ultimate Line Sources (Functional Class-Principal Arterials) - - - - - - - - - - - - - - 60

FIGURE 20. Ultimate Line Sources (Functional Class-Principal Arterials) - - - - - - - - - - - - - - 62

FIGURE 21. Ultimate Line Sources (Functional Class-Principal Arterials) - - - - - - - - - - - - - - 65

FIGURE 22. Ultimate Line Sources (Functional Class-Principal Arterials) - - - - - - - - - - - - - - 67

FIGURE 23. Ultimate Line Sources (Functional Class-Minor Arterials) - - - - - - - - - - - - - - - - 69

FIGURE 24. Ultimate Line Sources (Functional Class-Minor Arterials) - - - - - - - - - - - - - - - - 71

FIGURE 25. Ultimate Line Sources (Functional Class-Minor Arterials) - - - - - - - - - - - - - - - - 73

FIGURE 26. Emissions Summary for Freeway Corridor Diversion - - - 81

FIGURE 27. Emissions Summary for Parallel Arterial Diversion - - 84

FIGURE A-1 Program GIN Flowchart - - - - - - - - - - - - - - - - - 136

FIGURE A-2 Program RUMMY Flowchart - - - - - - - - - - - - - - - - 138

CHAPTER I

INTRODUCTION - STUDY DESIGN

CHAPTER I

INTRODUCTION - STUDY DESIGN

A. INTRODUCTION - OBJECTIVES OF RESEARCH

The study of pollution concentrations in a metropolitan area requires accurate characterization of pollution emitted due to the presence and operation of transportation corridors and grids, termed line sources. Accurate reporting of emissions depends on efficient monitoring of traffic flow and system design and location parameters critical to the emission process, in addition to adequate characterization of vehicular emissions under a range of operating conditions.

The objective of this research is to develop a methodology which documents the bases and criteria for determining which major freeway and arterial links should be considered emission line sources in a metropolitan area, and their geographic and temporal sensitivity to frequency and duration of monitoring. In addition to developing the methodology, it is to be verified through testing in the St. Louis Air Quality Control Region, determining specifically what links in this region shall be considered as line sources. In accomplishing the above, several specific performance objectives will be attained, which are:

a.) Obtainment and documentation of the most recent traffic data relevant to emissions phenomena for the St. Louis Region.

b.) Development of the methodology, and use of the above data to estimate emissions levels, through the use of the Department of Transportation model SAPOLLUT, which computes aggregate emissions and concentrations of CO, NO_x and HC for a traffic network. Detailed discussion of the model operation as used in this research is found in Chapters III, IV and Appendix A.

c.) Additional conceptualization of the methodology to formulate a sensitivity analysis which analyzes emissions information provided by different combinations of line source components, and allows comparison of information output vs. different specifications of traffic network inputs.

d.) Verification of the sensitivity analysis on the St. Louis Area, ultimately yielding appropriate specifications of emission line sources in the area.

B. LIMITED LITERATURE SEARCH

The objective of a limited literature search into traffic behavior and air pollution emissions in a project such as this one is to reinforce basic knowledge of relationships of emissions to key traffic behavioral variables. In so doing, the search allows the research team to see the rationale for their model building, its particular relationship to emissions stimuli, and to develop an overview and fluency with the traffic engineering literature dealing with the problem.

1.) Relevance of Air Standards

A basic research program with such a broad and intensive scope as the RAPS program is interested in accurately uncovering the phenomena of behavior of line sources and their resultant emissions, and the part these emissions play in the region-wide emissions problem. In so doing, the capability exists to add to basic knowledge which may ultimately lead to improved strategies for meeting ambient air standards.[1]

The highway system acting as a line source may act as a primary cause of CO. It may be a contributor to NO_x and HC emissions. Certain aspects of the highway transportation system will now be investigated in relation to these.

2.) Relationships of Emissions to Key Traffic Engineering Stimuli

The pollutants of CO, HC and NO_x have documented associations with speed.[2] Results of recent research on such associations is graphically shown in Figures 1, 2, and 3. These figures are the result of developed equations of:

$$\mathrm{LN\ HC} = A + B\overline{S} + C\overline{S}^2 \text{ in grams/mile}$$

$$\mathrm{LN\ CO} = A' + B'\overline{S} + C'\overline{S}^2 \text{ in grams/mile}$$

$$NO_x = A'' + B''\overline{S} \text{ in grams/mile}$$

In the above, $\overline{S}$ is the average speed of the driving sequence. To determine the speed correction factor at any particular speed in the range of 15 to 45 miles per hour, a ratio of the above equations is used. The emissions are determined at the desired speed and ratioed with the emissions at a speed of 19.6 miles per hour, the average speed over the federal driving schedule.[3] Figure 1 represents vehicle model year 1968 in low altitudes, Figure 2 represents the 1968 vehicle model year in Denver, and Figure 3 represents the 1971 model year in Denver. It should be noted the relationship is quadratic with respect to HC and CO, and linear with respect to NO_x, yielding decreasing emissions with increased average route speed for HC and CO, and increasing emissions of NO_x with increased average route speeds.

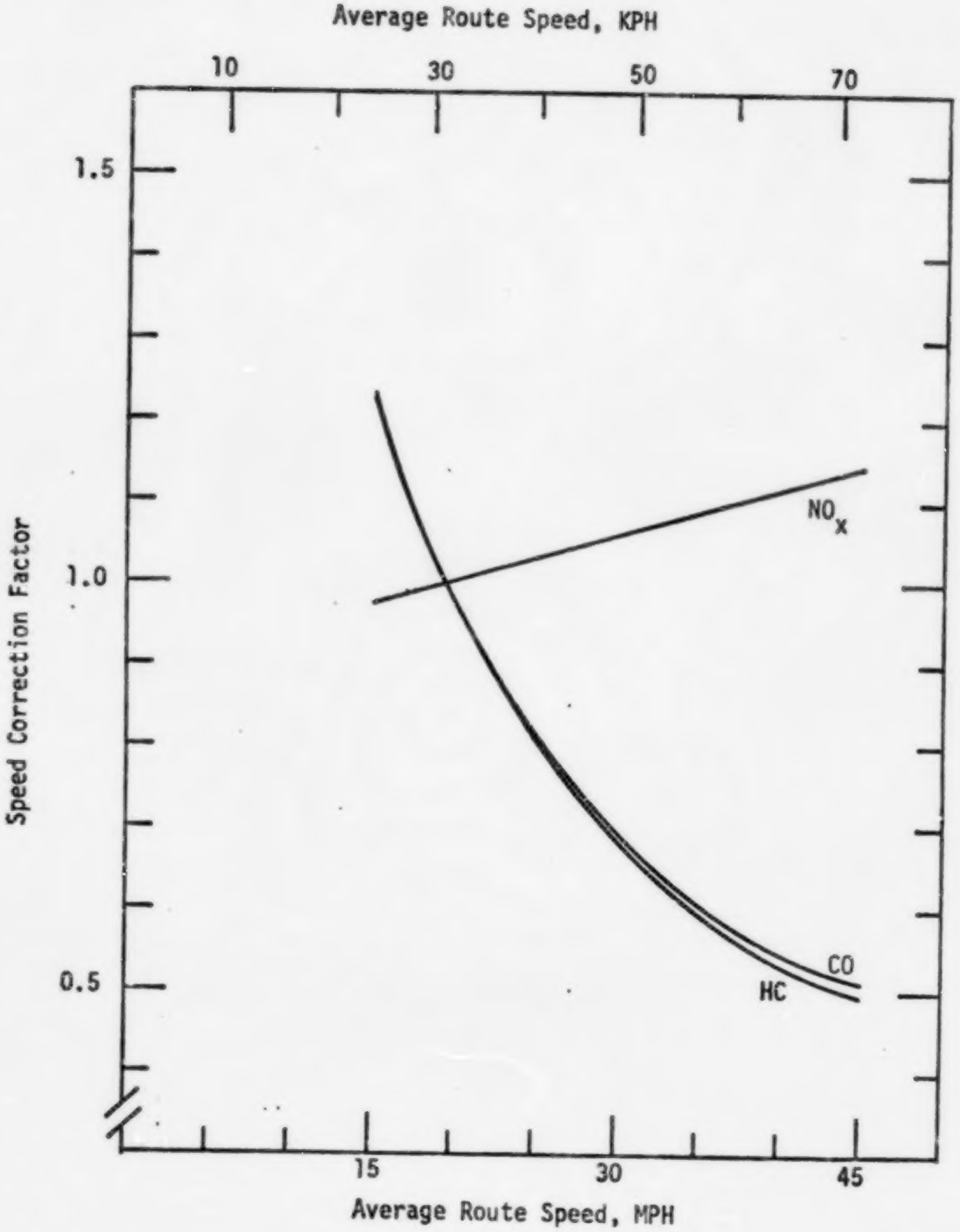


FIGURE 1. Speed Correction Factors for 1968 Model Year Vehicles in Low Altitudes

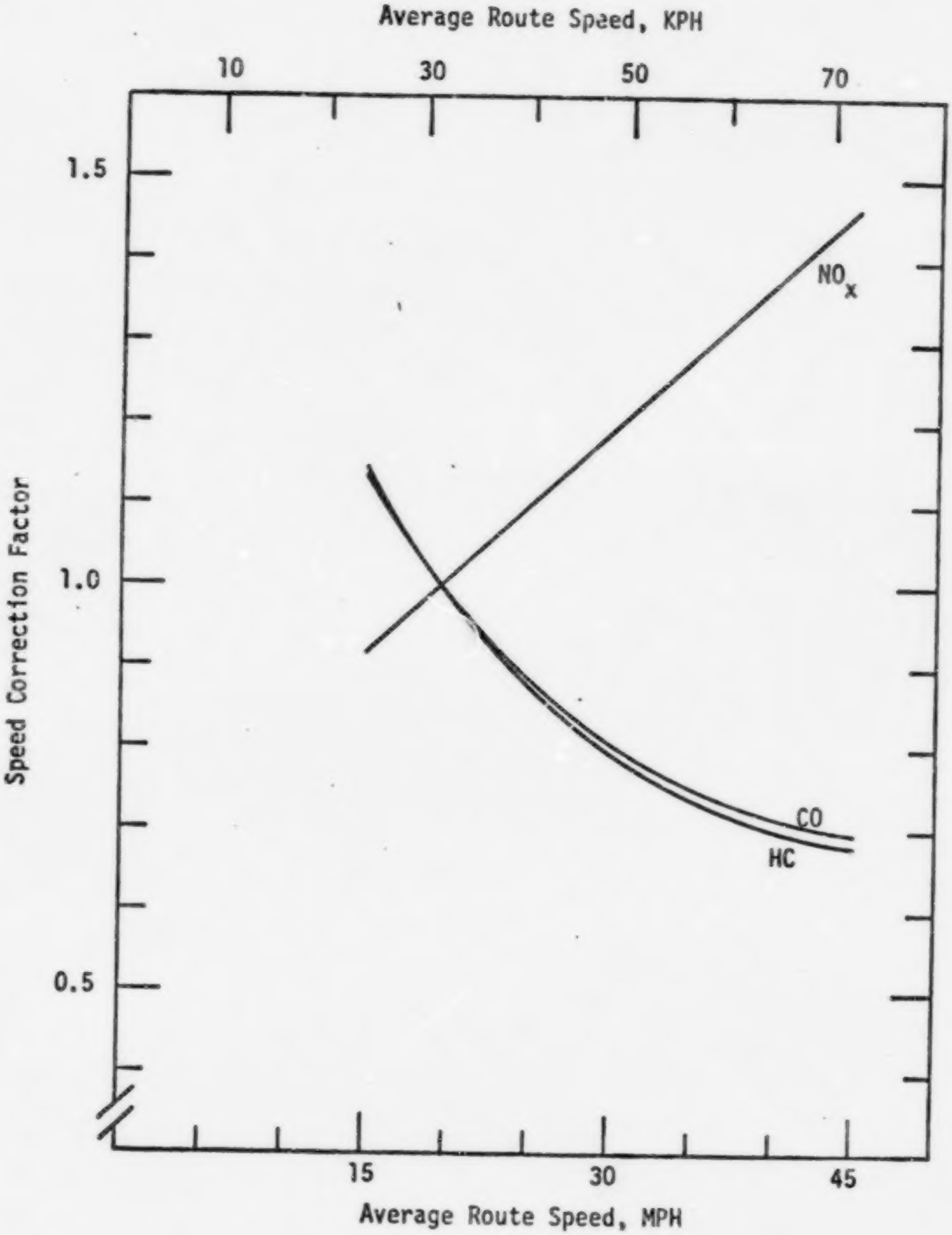


FIGURE 2. Speed Correction Factors for
1968 Model Year Vehicles in Denver

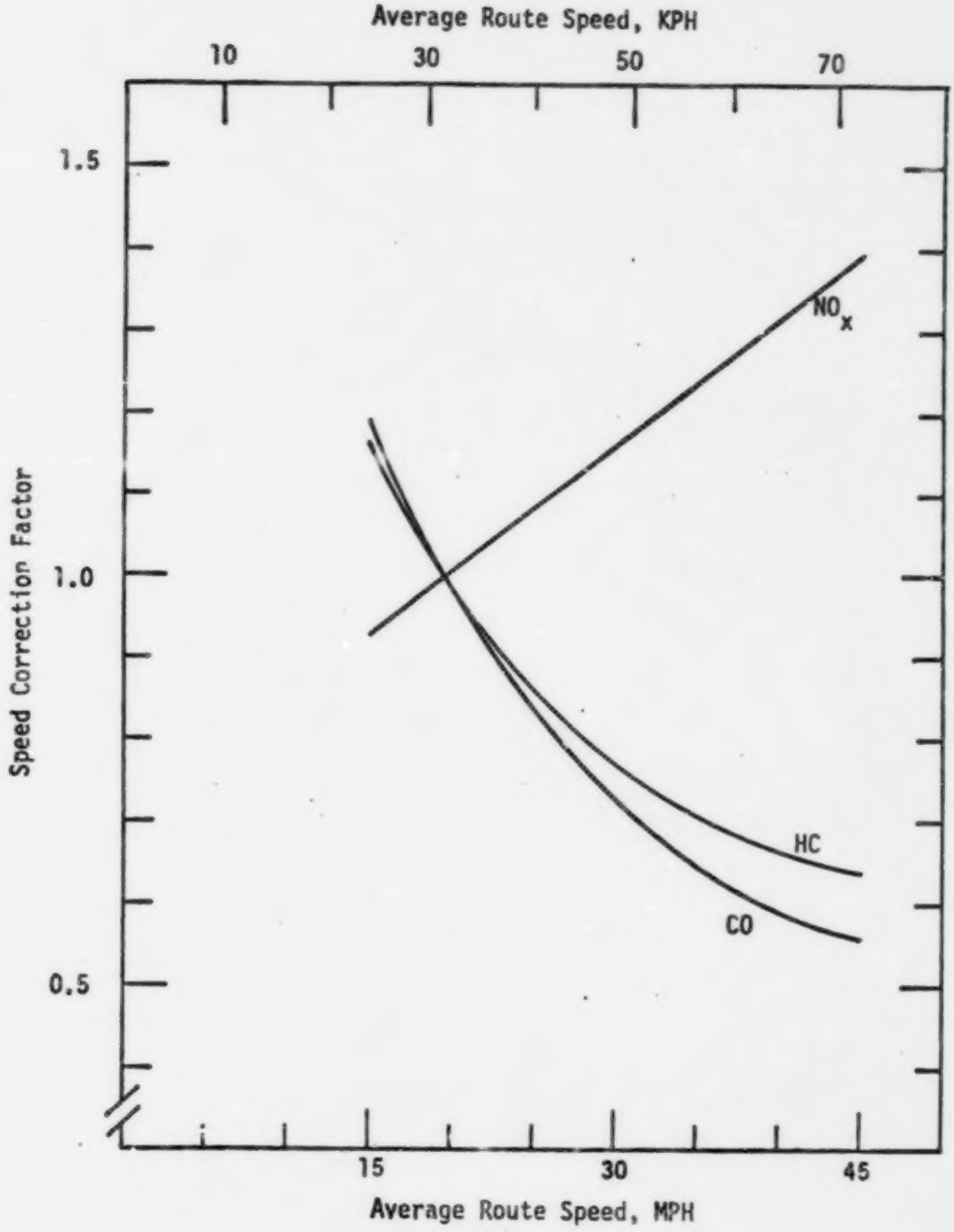


FIGURE 3. Speed Correction Factors for
1971 Model Year Vehicles in Denver

A further finding is that complex highway design configurations, unique localized meterology, presence of topography and rough terrain and downtown or high-rise street canyons play readily identifiable, but relatively less understood roles in air quality. In the simplest sense, average speed and vehicle miles of travel on a link are relevant inputs as indicators of CO, HC and NO_x emissions. The realistic design, environmental and neighborhood attributes modify the impact of these two basic stimuli on air quality, and the mechanics of these modifications are not developed in depth in the basic research to date. Figures 4, 5 and 6 are offered as visual examples of research output of the effect of geometric configuration on air quality.[4] A further behavioral input, closely related to average speed, is the smoothness of traffic flow and capability of avoiding traffic congestion effects. Figure 7 shows the concentrations for smooth, uninterrupted flow of 30 mph of typical freeway movement versus higher emissions induced by poor signal timing, pedestrian and parking interference which increases delay on a typical interrupted flow arterial street operating poorly.[5] As such, from a traffic engineering point of view, V/C ratios and acceleration noise parameters of the traffic stream are relevant to emissions levels.

In conclusion, the literature search revealed:

1.) The basic stimuli of emissions to be well documented against inputs of average speed and VMT for CO and HC, with more questionable data and relationships with respect to NO_x.

2.) Further complexities in air quality overlaid on the above when cut, fill, and complex cross section and geometric design configurations are included, as illustrated in Figures 4, 5 and 6.

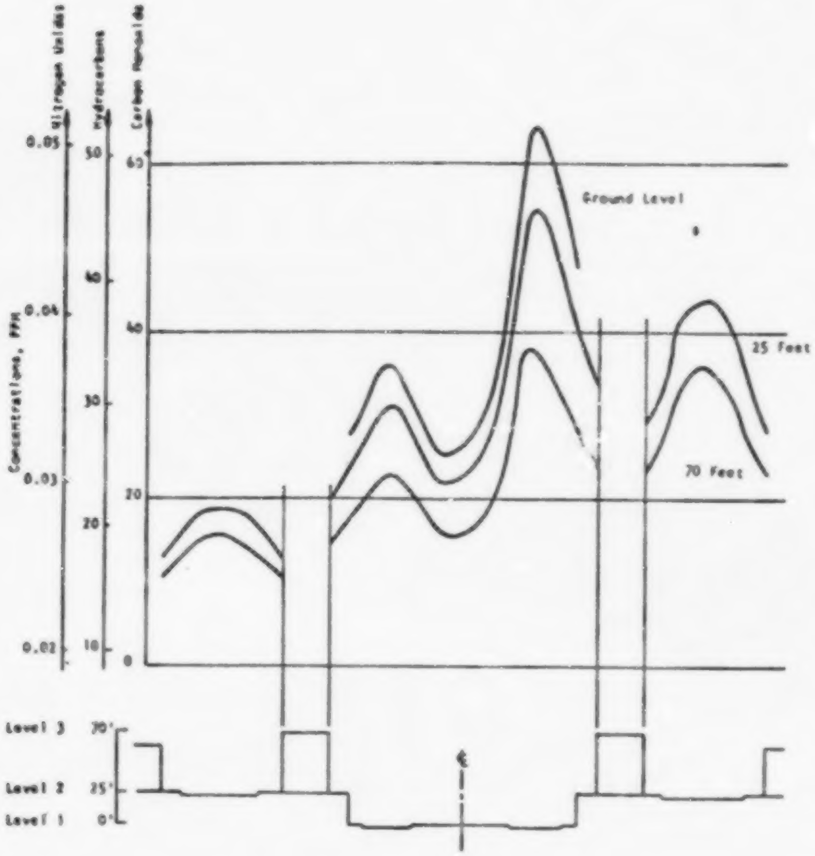


FIGURE 4. Pollution Levels Along Transverse Street Cross Section of Centered Expressway with Joint Development Structures

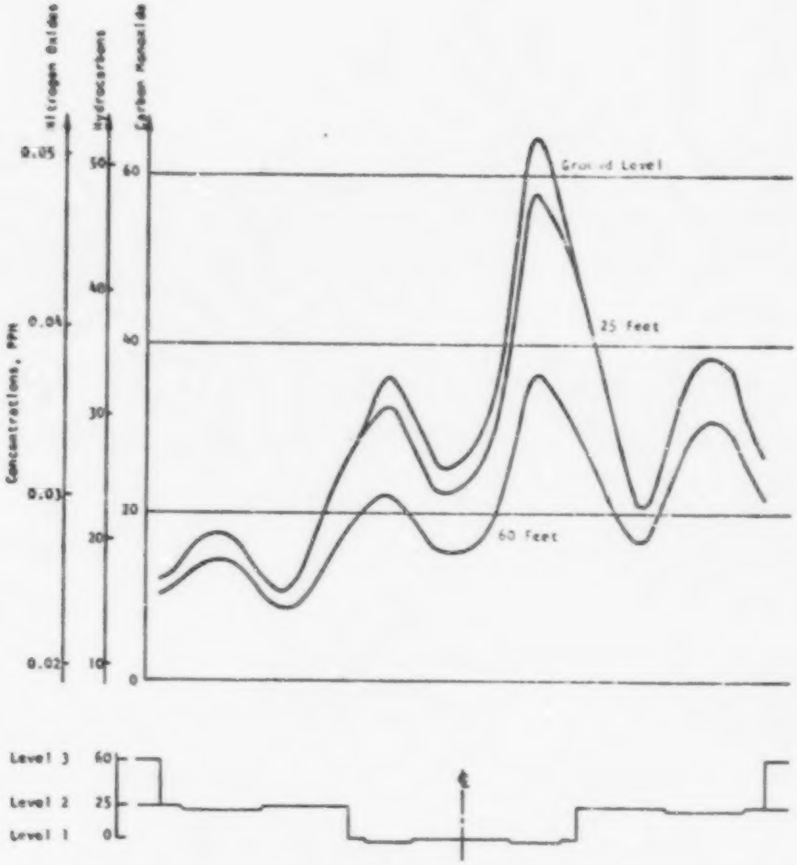


FIGURE 5. Pollution Levels Along Transverse Street Cross Section of Centered Expressway Without Joint Development Structures

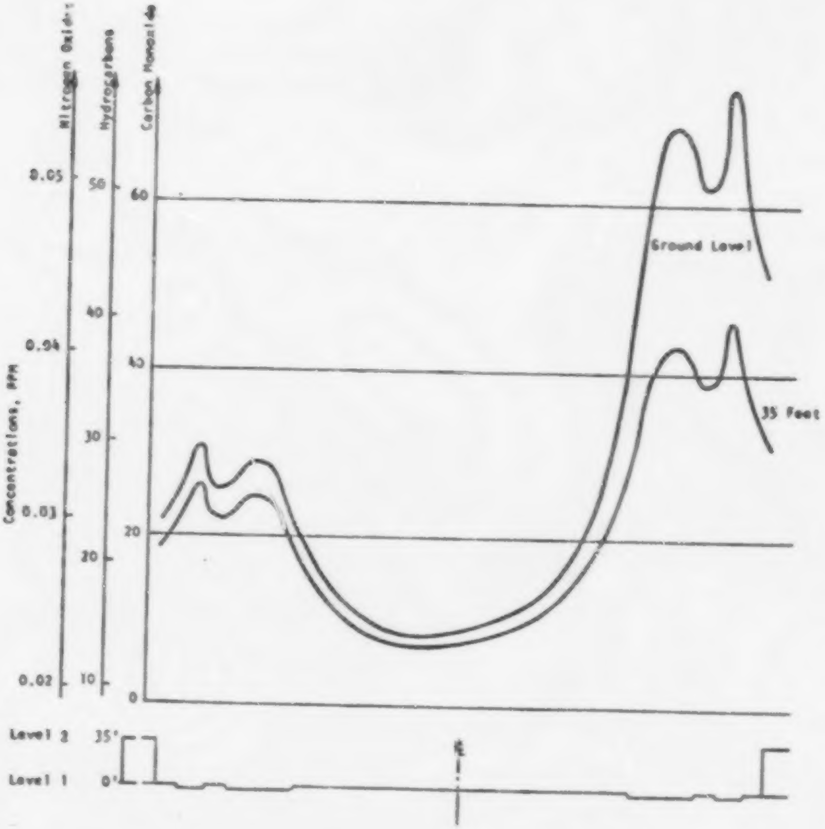


FIGURE 6. Pollution Levels Along Transverse Street Cross Section of Centered Expressway-Boulevard

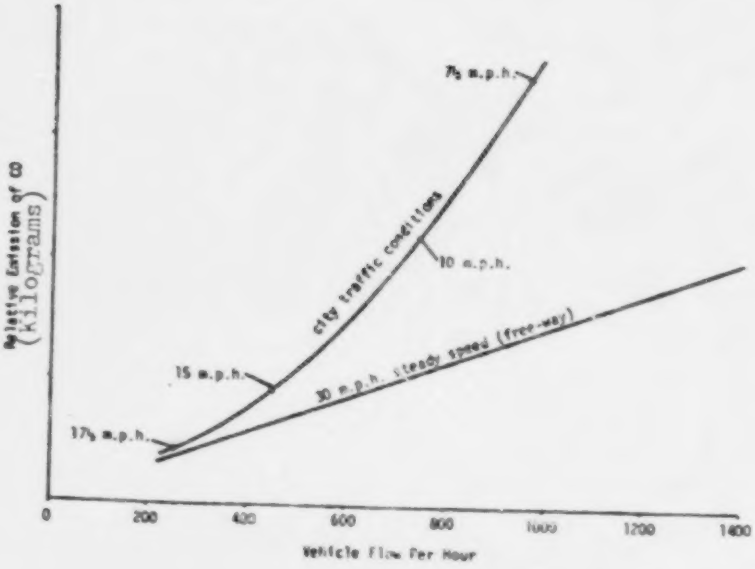


FIGURE 7. Comparison of City Street and Freeway Conditions

3.) Further complexity in emissions when system delay from congestion is introduced, as illustrated in Figure 7.

4.) Further complexity in air quality when overlaid by local, uniquely complex topography and terrain, and localized unique meterologic conditions.

5.) The apparent need for further basic research on line sources where such complexities in 2-4 above are introduced. That is, further research into locating them, stratifying their attributes, classifying them in an orderly data system, and relating their attributes to their resulting link emissions and the air quality of their locale.

C. FORMAL RESEARCH WORK PLAN

1.) Emissions and Air Quality-Related Traffic Flow Research Aspects

In light of the previous literature search, it has been categorically found that volume, or vehicle miles of travel, and average speed are critical inputs which relate to emissions of nitrogen oxides, carbon monoxides and hydrocarbons. However, exhaustive use of typical traffic flow data related to the above two inputs should allow a refined and meaningful statement of flow phenomena and traffic systems design which pollution output is sensitive to. Thus, a short discussion of such flow-related parameters is warranted, to demonstrate their categorization as inputs:

Volumes - Average Daily Traffic and peak hour volumes, historically as indicators of use of the facility.

Average Travel Speed - As an indicator of efficiency of the facility and adequacy of design.

General Interzonal Origin-Destination Patterns - As a regional mapping of incidence of travel, and proximity of travel paths to other regional activities.

Functional Classification of Highways - Classed as whether freeway, arterial, collector or local, as an indication of importance and frequency of use and level of design standards employed.

Delay Information - which modifies or refines information on average speed, above, through studies of volume to capacity ratios, travel time profiles, travel time contours, or waiting time or delay contours. Locations are detected in the system where speeds are radically altered due to delay and congestion.

Locations of Design Related Phenomena - such as extremely complicated route or interchange configurations, and areas of cut or fill, or frontage roads with structures, which induce localized alterations in air quality and emissions, the latter when average speed is modified due to the design phenomena.

Unique Areas of Progression - in addition to areas which can be reviewed from speed and delay information as stated above, these are unique in the network, in that some engineering or planning alteration exists to eliminate congestion by specific means with highly predictable results, such as one-way street flows, or progressive signalization, thus allowing atypical consistency in volumes or average speeds, with stable emissions output.

Areas of Critical Land Use Adjacent to or Within the Network - The first type is an area adjacent to the traffic system which is a highly sensitive land use to emissions output and local air quality, or a land use type such as industrial, which supplements and confounds the emissions level and air quality in the vicinity of the corridor. The second type is the downtown or core area, or like areas of high-rise, high-density buildings. The building heights or "street canyons" affect air quality in the vicinity of the grid and corridor sources.

Vehicle Mix - the composition of traffic, in terms of percentage of autos, intermediate size trucks and large size trucks is relevant, due to differing emissions from vehicle type, and the impact of the traffic composition on average speed and traffic flow throughout a link. The composition of vehicles by age also determines the level of emissions from the traffic stream.

Frequency of Monitoring - all links under study will encompass some or many of the above flow related phenomena which have an impact on emissions and/or air quality. The frequency of observing such network components with respect to adequate characterization of CO, NO_x, and HC information is critical. Typical choices of duration of traffic volume counting periods include 1, 8, 12, 24 hours, weekly, and peak-off peak combinations.

Thus, the above considerations are relevant to comprehensively using traffic flow information to develop the "optimal" network inputs for specifying emissions line sources. Use of this information may be characterized by the following three dimensional array in Figure 8.

The research proceeds by essentially categorizing each apparently relevant link component with respect to the above array, then testing and trading off combinations of these with respect to emissions levels to ultimately produce a set of line sources. The process proceeds interactively, making full use of local traffic engineering knowledge about network components, yet developing the taxonomy in a rigorous and consistent logic.

2.) Specific Work Plan of Research

To accomplish the stated objectives, and develop the output discussed above, a six-phase work program has been pursued, as shown in Figure 9.

Phase 1 has four tasks, which were carried on simultaneously. Task 1.1 consisted of review of the flow aspects discussed above with respect to their impact on emissions. Tasks 1.2 and 1.3 included the procurement of St. Louis Air Quality Control Regional Traffic data, and review of important links and their traffic operating attributes (Figure 8) with local professionals. Through the principal investigator's local knowledge and contacts, use was made of East-West Gateway Regional Coordinating Council professionals, and engineers with Missouri State Highway Department, Illinois Department of Transportation, and St. Louis, St. Clair, Madison and other appropriate county engineering personnel. The results of 1.2 and 1.3 yielded realistic insights into the operation of corridors and arterial highway grid components. In Task 1.4, the traffic input and emissions output aspects of the model SAPOLLUT was reviewed, and the model was procured and put on the Washington University Software Library.

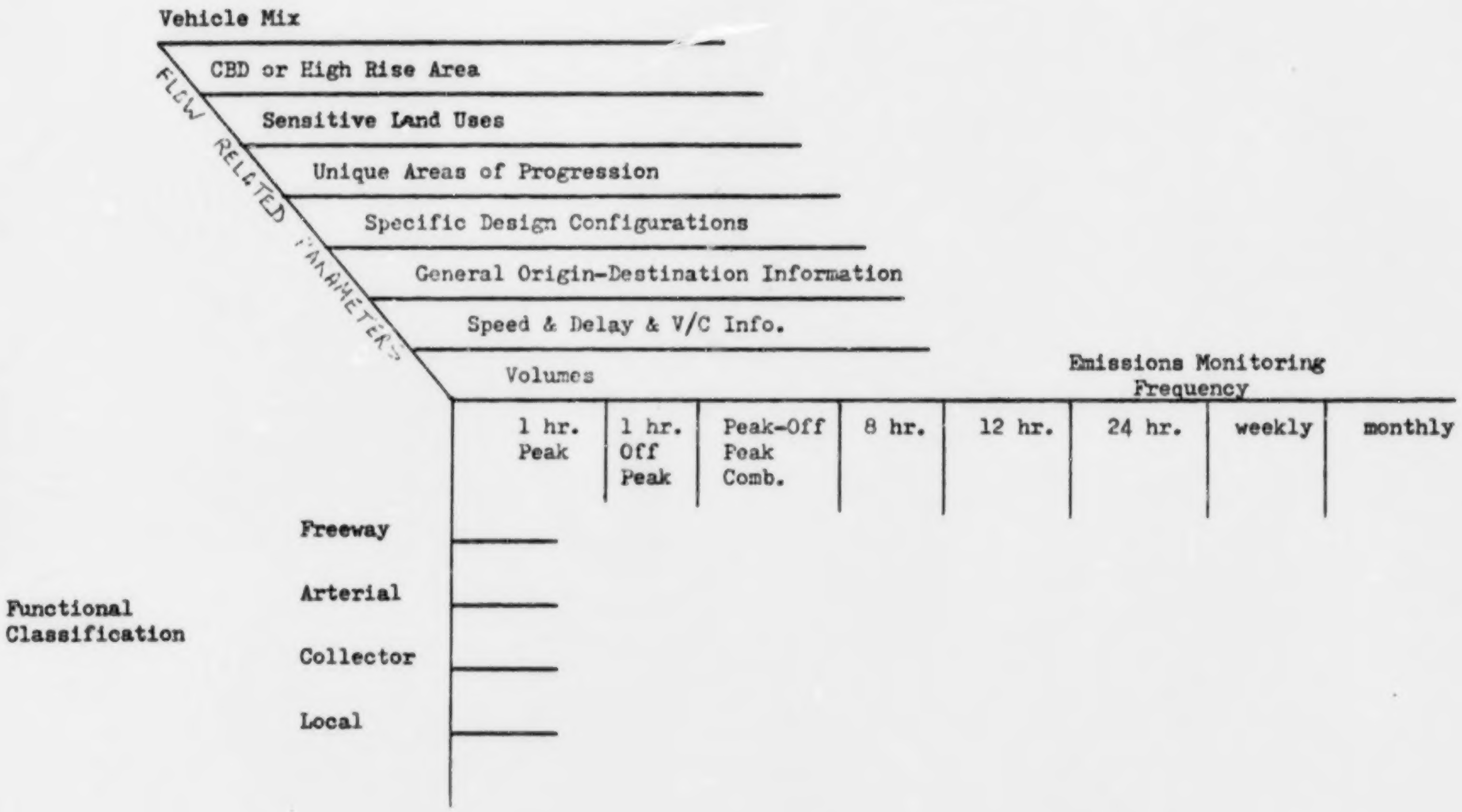


FIGURE 8. Flow Parameters Related to Emissions and/or Air Quality Phenomena

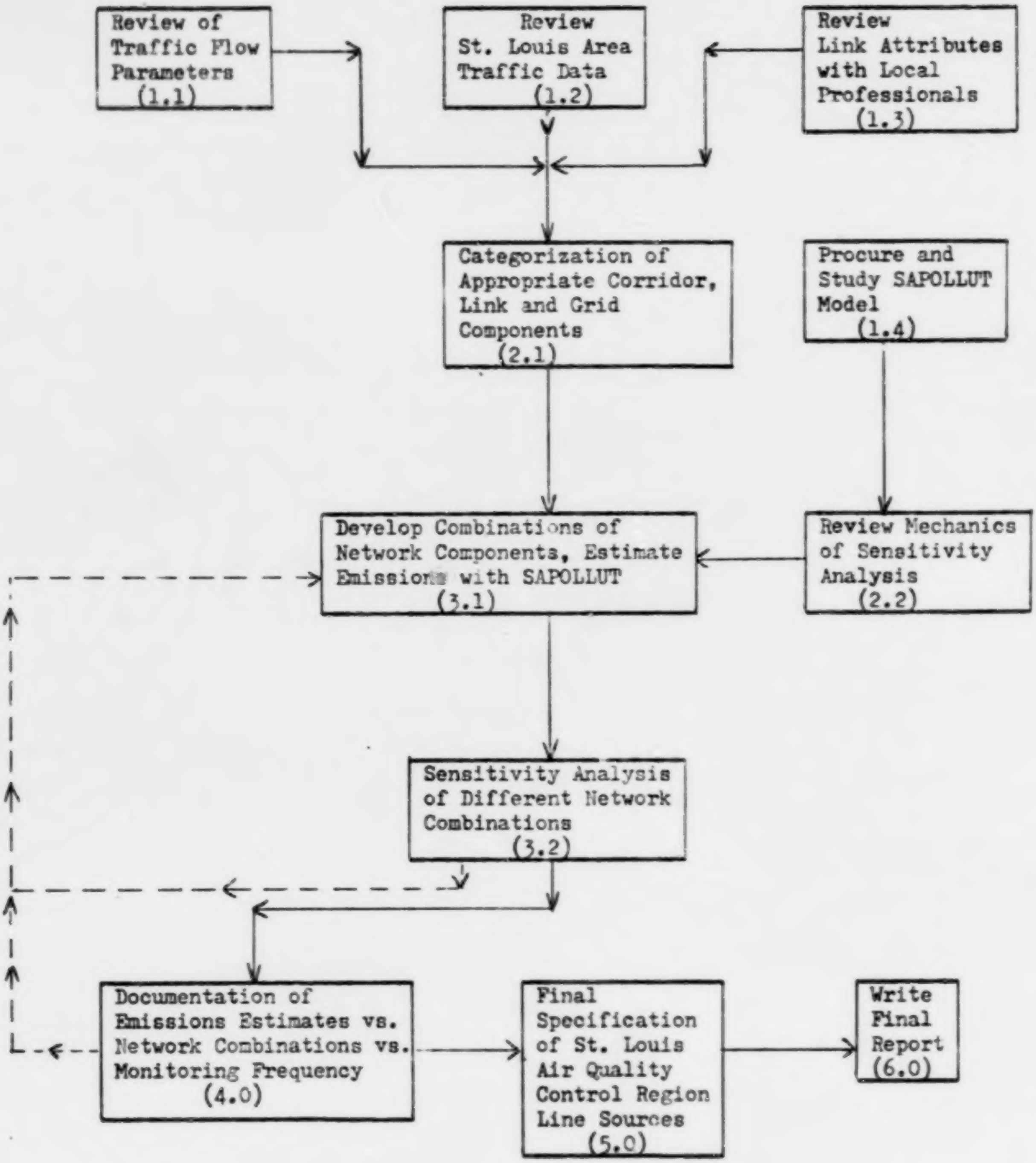

Review of Traffic Flow Parameters (1.1)
Review St. Louis Area Traffic Data (1.2)
Review Link Attributes with Local Professionals (1.3)
Categorization of Appropriate Corridor, Link and Grid Components (2.1)
Procure and Study SAPOLLUT Model (1.4)
Develop Combinations of Network Components, Estimate Emissions with SAPOLLUT (3.1)
Review Mechanics of Sensitivity Analysis (2.2)
Sensitivity Analysis of Different Network Combinations (3.2)
Documentation of Emissions Estimates vs. Network Combinations vs. Monitoring Frequency (4.0)
Final Specification of St. Louis Air Quality Control Region Line Sources (5.0)
Write Final Report (6.0)

FIGURE 9. Research Work Plan

Phase 2 included two overlapping tasks. The initial task, 2.1 categorized appropriate corridors, links and street grid components with respect to the flow phenomena illustrated in the previous three-dimensional array. The coding was developed so that a complete set of descriptors exists for each corridor, link or arterial street grid level conceptualized and developed as input. Overlapping with this, task 2.2 familiarized the study team with the sensitivity analysis, and the mechanics of its performance in order to assure continuity between Phase 3 and later phases.

Phase 3 had two tasks. Task 3.1 developed levels and combinations of network hierarchial components as inputs to studying emissions. The following sequence of components were developed for use with SAPOLLUT and sensitivity testing:

Round 1: All freeway corridors, link components broken up by average speed differentials and volume differentials.

Round 2: All freeway corridors, additional breakdown by sites of specifically complex configuration.

Round 3: Addition of the arterial street grid to above, broken down by speed, delay and volume differentials.

Round 4: All the above, additional breakdown by arterial sites of specifically complex configuration.

Round 5: Addition of refined locations adjacent to sensitive land use areas, and areas of exceptional progression.

Round 6: All of the above, cross classified by vehicle mix.

Thus, the approach is to ultimately yield a descriptive network of line sources N, which is composed of

$$N = \sum_{i,j,k,m,n,o,p,q,\ldots\ldots t} \ell_{ijkmnopq\ \ldots\ldots t}$$

where ℓ is a specific link or network component and i, j, k, m, n, o, p, q ..... are its flow parameters shown in the three-dimensional array, and t is the monitoring frequency. At each of the above rounds, the network could be input to SAPOLLUT, and emissions information estimated. The network is synthesized in a sequential manner through the several rounds, to develop clarity about its composition and emissions output, allowing for a more orderly sensitivity analysis.

Task 3.2 articulated changes in the above synthesized network and site monitoring frequency. From knowledge of the local area, specific link and network components developed through all of the above rounds were removed or added, noting through the use of SAPOLLUT in a sensitivity analysis, the change in resulting emissions information. The sensitivity analysis of the coded link and network components was developed in a batch software format, to allow a certain programmed sequence of network alterations to occur. This process was hooked with SAPOLLUT, to allow network input operations and emissions estimation to occur in one continuous software run.

Phase 4 documented the results of the use of SAPOLLUT and the sensitivity analysis carried on in 3.2. Reference to Figure 9 shows feedback and interaction across 3.1, 3.2 and 4 to adequately formulate test, converge and document the above processes.

Phase 5 utilizes the above array of sensitivity and convergence information and specifically states network component locations, their frequency of emissions monitoring, and the required traffic flow-related data. This specification defines the emission line sources for the St. Louis Air Quality Control Region.

Phase 6 combines previous conceptual analysis, the computer software, associated network synthesis, use of SAPOLLUT and the sensitivity analysis and its results, with specifications for refinement and further research into a final written report contained herein. The following text will elaborate on data collection, software development, use of SAPOLLUT, sensitivity analysis and definition line sources, and provide appropriate appendices on software documentation and data formats.

Footnotes Chapter I

[1] *Federal Register*, Volume 36, No. 84, Friday, April 30, 1971.

[2] Scott Research Laboratories, Inc., *Development of Representative Driving Patterns at Various Average Route Speeds, EPA No. 68-02-1301 (6-73)*. February 11, 1974, San Bernadino, California.

[3] *Ibid.*, pp. 3-1 through 4-18.

[4] Sturman, G. M., *The Effect of Highways on the Environment*, May, 1970.

[5] Steering Group and Working Group Appointed by the Minister of Transport, Great Britain, *Cars for Cities*, 1967.

CHAPTER II

DATA DEVELOPMENT

An assessment of highway line sources with respect to emissions requires that the road network under study be classified according to a set of parameters that allows appropriate hierarchial analysis, since some links will be much more critical from an emissions standpoint than others.

The data collection effort focused on those areas designated as urban and urbanizing. The East-West Gateway Coordinating Council defines these areas to include the City of St. Louis, St. Louis County, and parts of St. Charles and Jefferson Counties in Missouri. In Illinois part of Monroe, and Madison and St. Clair Counties are included.

Roadway data was collected within this area in light of emissions and their sensitivity to highway functional class, volume and composition of vehicles present, and the operational characteristics of vehicles related to both traffic volume and average speed alterations due to roadway alignment and profile. Other data collected, such as the intensity and type of the adjacent land use is relevant, along with certain highway design characteristics, to the localized air quality.

A number of agencies were contacted to compile the inventory. They included the East-West Gateway Coordinating Council, Missouri State Highway Department Jefferson City Office and St. Louis Office, the Region VII Office of the Illinois Department of Transportation, the Office of the Deputy Commissioner of the City of St. Louis Street Department, St. Louis County Division of Highways and Traffic, and the City of St. Charles.

A working set of highway links was established through the use of East-West Gateway's 7001 link-node map for the entire region under study. Actual street names for all links were recorded from maps provided by the Auto Club of Missouri.

The initial major data collection effort was for the freeway functional class. Volume and vehicle attributes sought for each link were average daily traffic, peak hour traffic, hourly distribution of traffic, percent of heavy duty vehicles, and the directional distribution of traffic. All the above were obtained for the Missouri counties except percent heavy duty vehicles. However, in Illinois, only average daily traffic and percent heavy duty vehicle data was available.

Link attributes sought to describe vehicle operating characteristics were the volume to capacity ratio (V/C), peak hour speed by direction, off peak speed by direction, frequency of complex interchanges, lane drops and existing freeway bottleneck sections. The capacity information obtained from East-West Gateway was a representative daily capacity factored down to obtain a peak hour V/C ratio at level of service E.[1] An hourly V/C ratio table was given in the SAPOLLUT users manual based on an hourly speed distribution. Current peak hour speed data by direction was available for 75% of the area freeway links from East-West Gateway. Through the cooperation of the Illinois Department of Transportation and local agencies in St. Louis and St. Louis County, a complete set of links with complex interchanges, lane drops, and major freeway bottlenecks was compiled. The study team drove the network to collect information on roadway topography as a freeway link descriptor. Four terrain types were categorized: high fill, deep cut, rolling terrain, and level terrain.

As a final set of link descriptors for the freeway functional class, land use by type and intensity was sought. East-West Gateway provided an area map delineating high density regionally oriented land uses. Types included commercial, educational, medical, recreational, and airport.

The next major data collection effort was for principal arterial roadways. These roadways are characterized by a minimum number of intersections at grade. Such intersections are typically designated to provide channelization and signal synchronization to enhance the traffic movement along the arterial. The link attributes sought to describe volume and vehicle composition were as before, average daily traffic, peak hour traffic, hourly distribution of traffic, percent of heavy duty vehicles, and the directional distribution of travel. The same data gaps that existed for freeways exist for principal arterials in this attribute set. In addition to volume to capacity ratios, peak hour directional speed, off peak directional speed, lane drops, and general roadway bottlenecks were collected as link attributes for vehicle operating characteristics. Further, information concerning the degree of progressive movement was sought. Progressive movement is typified by a continuous flow of a platoon of vehicles over long stretches of highway. Such movement can be induced by the type of signal systems employed at intersections and the distribution of one-way streets. It is desirable to separate out links that have progressive movement since the degree of vehicle delay is much less than on arterials without it. Attributes for progression included links with pre-timed signal systems, physically interconnected signal systems, and one-way street flows. The City of St. Louis, St. Louis County, Missouri State Highway Department, and the Illinois Department of Transportation provided us with complete information on this attribute set.

As in the freeway case, sensitive land uses were included as link descriptors. In addition to those already listed, the central business district was included as an area type in the inventory. This was done to aid in the delineation of an additional topography attribute, the categorization of street canyons.

The final data collection report was for minor arterial roadways. Such roadways provide for both traffic movement and land access. The data sought was the same for principal arterials and had the same data gaps.

In total, 28 link descriptors across three functional classes of highway were assembled. This data was compiled on an individual link basis, coded for keypunching and readied for input into the software system to be described in Chapters III and IV. The collection and coding format is illustrated in Appendix B.

Footnotes Chapter II

[1] Level of Service E represents operation of the system with volume at or near capacity. Operating speed is relatively low, flow is unstable and momentary stoppage occurs; the system is on the verge of complete jam and saturation with attendant congestion effects.

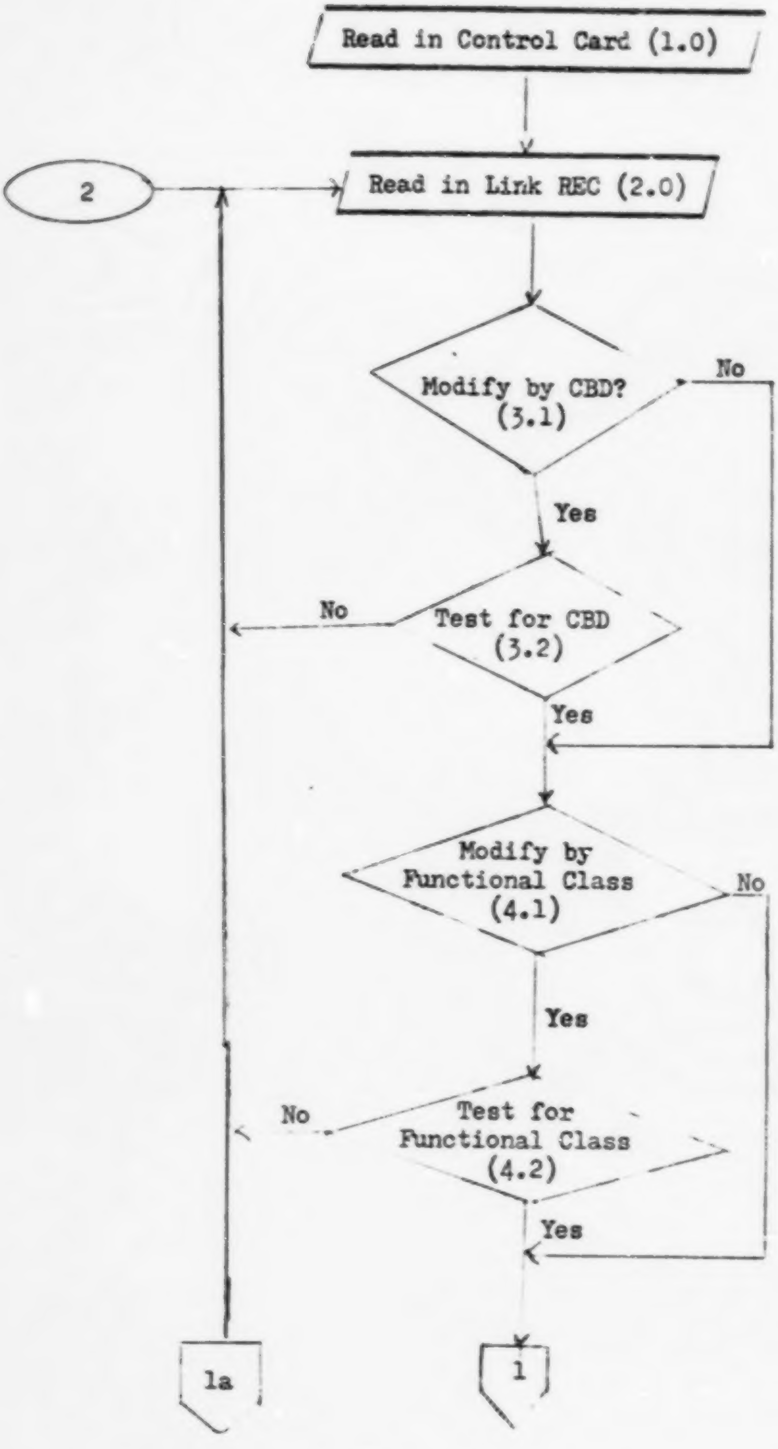
CHAPTER III

MODEL DEVELOPMENT

A. OVERVIEW OF MODEL LOGIC

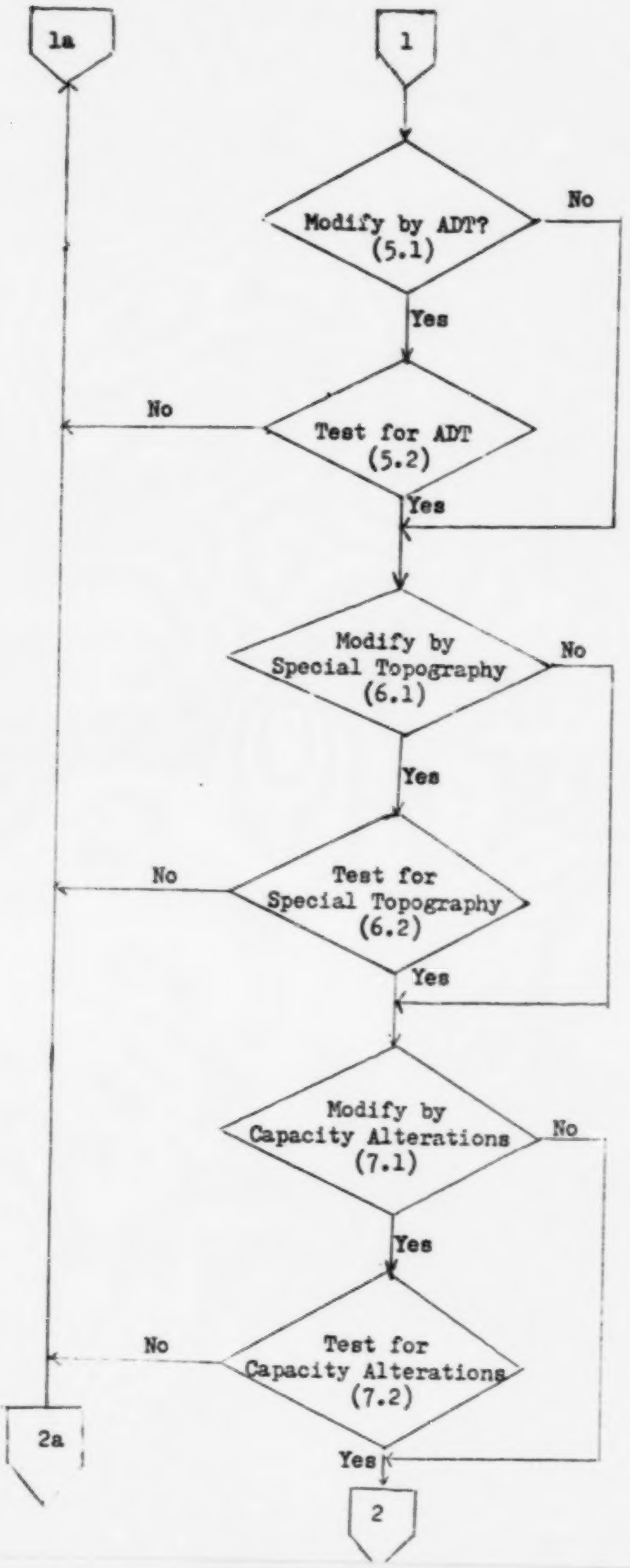
This chapter describes the logic construct of the network sensitivity model NETSEN, and its interface with the emissions estimation model SAPOLLUT. The flow chart of the master logic for the model NETSEN is shown in Figure 10. In general, the model works by defining a series of sequential tests of presence of network related attributes shown in steps 2.0-13.0. These are presence of the link within the Central Business District (i.e., the Downtown Core Commercial Area), functional class of the link, its ADT, presence of special topography, capacity alterations, presence of sensitive land uses, presence of progressive movement, speed difference, truck volumes, and V/C ratio. After reading the coded link data records in, with step 2.0, each link is tested to sort and classify it according to combinations of attributes present in it. Those groups of links thus containing certain combinations specified in the control card in step 1.0 are then output to SAPOLLUT for use in estimating emissions. A complete description of the software documentation is given in Appendix A. Two specific points are important in overviewing the logic at this point:

1.) The network and any link subset component of it can be tested at any level of data attributes relevant, from very gross descriptions containing only ADT information, to very refined descriptions of the network, classifying and locating all of the attributes shown in steps 2.0-13.0 on the network.

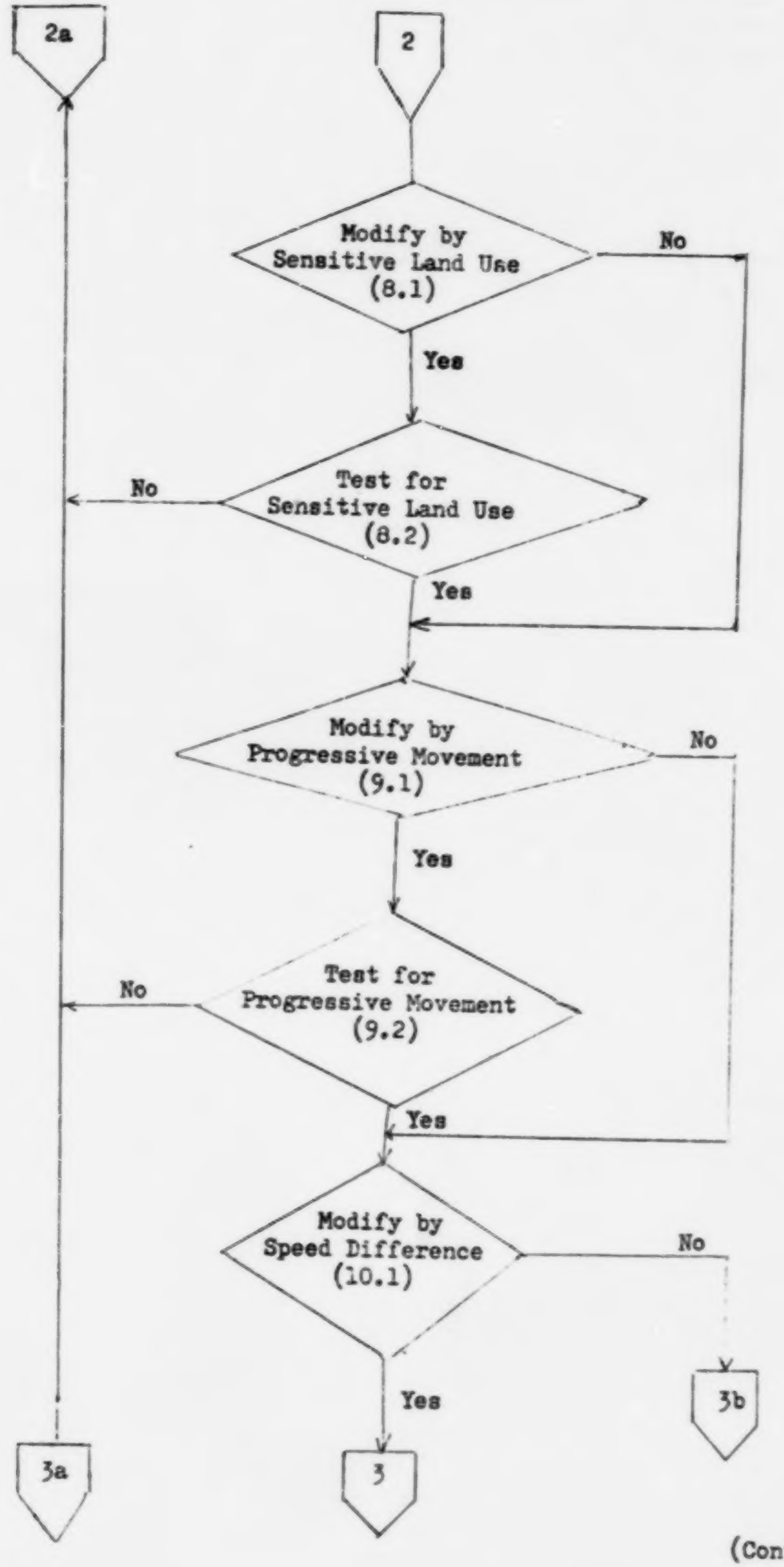

Read in Control Card (1.0)
2
Read in Link REC (2.0)
Modify by CBD? (3.1)
No
Yes
No
Test for CBD (3.2)
Yes
Modify by Functional Class (4.1)
No
Yes
No
Test for Functional Class (4.2)
Yes
1a
1

(Continued)

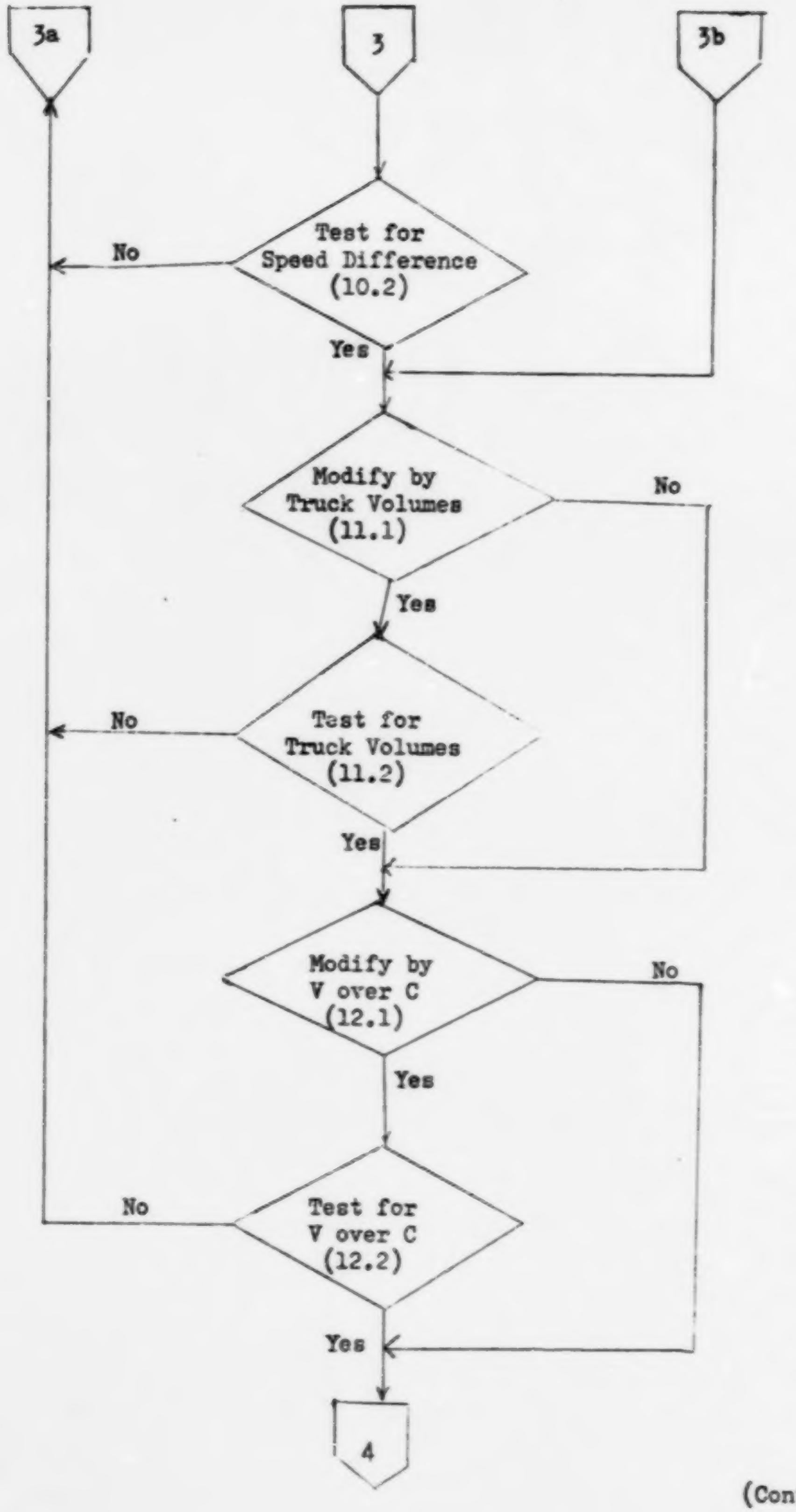
FIGURE 10. Master Logic of NETSEN Model


1a
1
Modify by ADT?
(5.1)
No
Yes
Test for ADT
(5.2)
No
Yes
Modify by
Special Topography
(6.1)
No
Yes
Test for
Special Topography
(6.2)
No
Yes
Modify by
Capacity Alterations
(7.1)
No
Yes
Test for
Capacity Alterations
(7.2)
No
Yes
2a
2

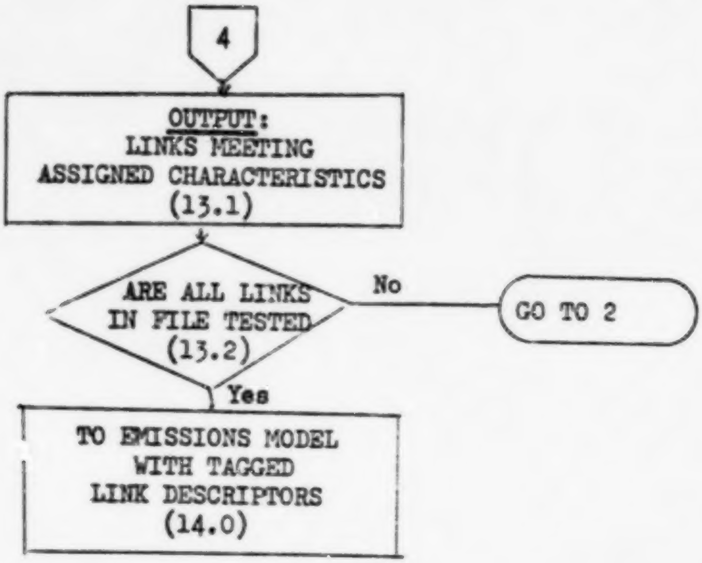
(Continued)


2a
2
Modify by
Sensitive Land Use
(8.1)
No
Yes
Test for
Sensitive Land Use
(8.2)
No
Yes
Modify by
Progressive Movement
(9.1)
No
Yes
Test for
Progressive Movement
(9.2)
No
Yes
Modify by
Speed Difference
(10.1)
No
Yes
3b
3a
3

(Continued)


3a
3
3b
Test for
Speed Difference
(10.2)
No
Yes
Modify by
Truck Volumes
(11.1)
No
Yes
Test for
Truck Volumes
(11.2)
No
Yes
Modify by
V over C
(12.1)
No
Yes
Test for
V over C
(12.2)
No
Yes
4

(Continued)


4
OUTPUT:
LINKS MEETING
ASSIGNED CHARACTERISTICS
(13.1)
ARE ALL LINKS
IN FILE TESTED
(13.2)
No
GO TO 2
Yes
TO EMISSIONS MODEL
WITH TAGGED
LINK DESCRIPTORS
(14.0)

2. The level of attribute refinement chosen to be tested for may be varied with the refinement of detail of data present on the network the user has access to, or the level of refinement deemed necessary for the user to study emissions. Thus, complete flexibility exists in describing the traffic related behavioral aspects of the network as related to emissions estimation.

B. SOFTWARE SYSTEM DEVELOPMENT

A discussion of the formal software system and interface with SAPOLLUT should be prefaced with brief mention of the traditional Urban Transportation Planning (UTP) background of SAPOLLUT. The implication is that the model was designed to link to the FHWA programming battery which performs the UTP process of trip generation, trip distribution and traffic assignment, with the attendant problem of using a loaded traffic assignment network versus actual ground counts.[1] The design of the UTP process makes it necessary to modify some software usage in order to use realistic ground counts in SAPOLLUT.

The completed software system correctly employing these modifications is shown in Figure 11. The system begins with the sequential file of the network link records of data attributes (1.1). The complete documentation of the format of this file is in Appendix A. The system branch containing program modules 1.2, 1.3 and 1.4 is an initialization routine executed only one time to set up the system's

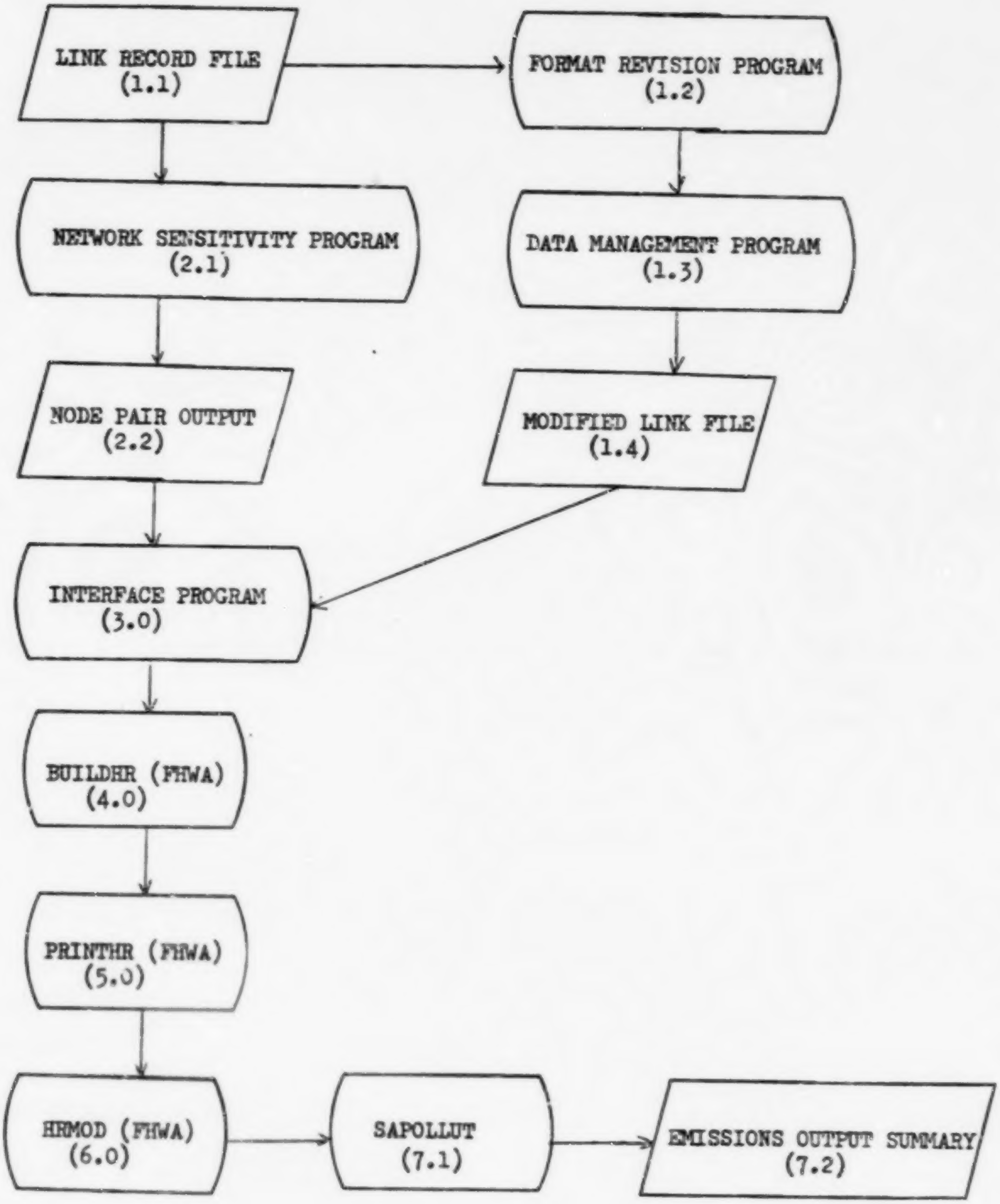


FIGURE 11. Traffic Emissions Software System

operation. The format revision program HRCVRT (1.2), takes the link record file as input and transforms it into output which will eventually be in a usable format for input into the FHWA program BUILDHR in step 4.0.

As such, module 1.3, referred to as the Data Management Program, accepts as input the link records from the Format Revision Program. The program creates what is called an indexed sequential data set. Essentially, this implies attaching a key to each link record so that it may later be retrieved with a single command, obviating a search procedure. The output of the program, termed a modified link (1.4) file, is essentially the same as its input except for the above keyed reorganization to speed access. It is important to emphasize that this program does not make any functional changes in the link records and its function could be performed elsewhere in the system. As noted earlier, this program is only executed once for all runs of NETSEN.

The next program in the software is the Interface Program (3.0), and as its name implies, it is the heart of the interfacing procedure. It accepts input from two places. First, it accepts a node pair output (2.2) from the NETSEN Program (2.1) which has passed all logic tests in that program. It then uses this node pair as a key to retrieve with a single statement the link record from 1.4 which is identified by the node pair. The program then processes the link by producing a dummy link to connect to its A-node if the previous link already processed does not have a B-node which is the same as the current A-node. The program then checks to see if the A-node is numerically less than the B-node, and if so the two are reversed. Further action takes the sum of the A-B volume count and the B-A volume count and places this sum minus 1000 in an A-B count location. The program then makes a series of edit checks to assure that valid links or dummy links do not violate any of the traffic assignment coding conventions for leg numbers and to assure that the proper count volumes are passed to SAPOLLUT. The output is a network compatible to the historical record building program, BUILDHR, in 4.0.

The next program in the software system is the FHWA BUILDHR program. The program accepts link records as input, and functionally, the program performs edit checking on them for consistency in coding, ultimately outputting a binary historical record for each link and also one for each node. The types of edit checking done by BUILDHR include checking for unusually long links, excessively large volume-to-capacity ratios as well as duplicate node and leg numbers.

Another FHWA program, PRINTHR (5.0), follows in the software system. The program accepts the binary historical records as input from BUILDHR and prepares a printed summary of information in the records which is useful in checking for proper operation of preceding programs as well as for interpreting the output of SAPOLLUT on the basis of a specific set of links. Although this program is not functionally necessary for operation of the system, it provides useful information at a small cost.

The final interface program preceding SAPOLLUT is the FHWA program, HRMOD (6.0). This program is necessary because of SAPOLLUT's orientation toward traffic assignment loaded networks. Although the basic historical record has ground count information included in it, SAPOLLUT can not use it in its storage location. It is necessary to relocate actual ground count data from their storage locations in the historical record to those storage locations where traffic assignment loads would normally be. The program HRMOD is used to shift the ground counts to the locations where the loads are normally situated. It then outputs this modified historical record to SAPOLLUT.

The last program in the software system is the emissions model SAPOLLUT (7.1). It receives the modified historical record from HRMOD and several control cards as input. It then proceeds to compute three types of emissions (HC, CO, NO_x) for three different area types (CBD, Central City, Suburb)[2] and two different functional classes, freeways and arterials, using vehicle miles of travel and average speed input, the latter developed by one of three alternative methods available to the program. The emissions output is currently available only in the aggregate, broken down by area type, hour of the day, and functional class across each emission type. By further dividing gross kilograms of emissions by vehicle-miles traveled it provides emissions in grams per vehicle-mile and grams per passenger-mile, given an average auto occupancy level.

In its current state the software system is fully automated in batch mode. Thus, when the network inventory is loaded onto a tape or disk data set and the initialization programs (Format Revision Program (1.2) and Data Management Program (1.3)) are run once, the system can execute several runs of NETSEN, examining the network at several levels of refinement, with one submittal to the computer. By providing a series of control cards to NETSEN, separate member data sets for each run are created, saving the individual sets of node pairs to be processed all the way through SAPOLLUT on successive runs through the system. This enables the user to rapidly analyze the network with a set of pre-determined runs. It should be emphasized that no manual interface is necessary during this process. The following chapter will demonstrate the flexibility and solution properties of the system operation in documenting line sources for the St. Louis Air Quality Control Region.

Footnotes Chapter III

[1] Program Documentation, Urban Transportation Planning, March 1972, Federal Highway Administration. A loaded network is defined as a transportation planning network in which the traffic volumes on various links are the result of theoretical computation. A ground count is defined as the actual recorded count of vehicles on a roadway link, generally made by mechanical counting devices.

[2] Central Business District is the downtown commercial core: the Central City is the non-commercial downtown core area, and the suburban area is the outlying area of lesser density.

CHAPTER IV

DOCUMENTATION OF EMISSION LINE SOURCES

A. Introduction-Issues in Defining Line Sources

As previously discussed, useful definition of line sources hinges on the capability to analyze the highway network and its traffic and design attributes at varying levels of detail, depending on the data availability and the level of spatial refinement sought in emissions information from SAPOLLUT. As such, this chapter demonstrates the development of a very unrefined definition of line sources, termed gross line sources, and the sequential refinement of such to a set of descriptors termed ultimate line sources. Each of these extremes of definition are consistent with the basic definition of a line source, given immediately below in Section B.

B. Basic Definitions-Delineation of Gross Line Sources

The following basic definition of a line source was employed in documenting emissions for the St. Louis Regional network:

> "the smallest segment of inventoried roadway depictable with a given specific set of attributes for the roadway."

At the grossest level, the line sources were broken down in the categories depicted by Table 1. The X's indicate which ADT ranges were used for functional classes of roadway. In addition, separate baseline runs were made to select all freeways, all principal arterials, and all minor arterials within these ADT classes. The emissions produced by this gross ADT breakdown of line sources are summarized in the following set of figures and tables for 24-hour periods:

1. Figure 12 represents those freeway links in each of the ADT ranges from Table 1. Table 2 presents vehicle-miles travelled (VMT), total emissions, and emission rates for freeways in each of these ADT ranges.

2. Figure 13 represents those principal arterial links in each of the ADT ranges from Table 1. Table 3 presents VMT, total emissions, and rates for principal arterials in each of these ADT ranges.

3. Figure 14 represents those minor arterial links in each of the ADT ranges from Table 1. Table 4 presents VMT, total emissions and rates for minor arterials in each of these ADT ranges.

A composite analysis of these tables leads to conclusions generally consistent with the literature, subject to subtle interpretation which must be employed when aggregating emissions information over all links under study in a particular functional class. Total kg of emissions over all categories (CO, NO_x, and HC) rank lowest for minor arterials, reflecting lowest VMT exposure. Both the freeways and principal arterials have very similar VMT totals. However, the freeways exhibit lower totals for CO and HC, and higher NO_x totals than the principal arterials, reflecting consistently lower average speeds on the arterials. The CO rates (grams/vehicle mile) show the most noticeable change across ADT ranges for all functional classes, with the most sharp changes associated with the last three ADT ranges in each class. This is apparently due to the distinct reduction in average speed associated with links at these particular ADT ranges nearing or exceeding saturation for their functional class. HC and NO_x, however, show generally stable emissions totals across all functional classes. The HC rate rises slightly, reflecting the aggregate impact across all links in the network of reduced average speed

ADT Ranges (Thousands)	Freeways	Principal Arterials	Minor Arterials
1-30	X		
30-40	X		
40-50	X		
50-60	X		
60-70	X		
70-200	X		
5-10		X	X
10-15		X	X
15-20		X	X
20-25		X	
25-30		X	
30-35		X	
35-40		X	
40-100		X	
20-40			X

TABLE 1

ADT RANGES USED FOR GROSS
LEVEL LINE SOURCE DEFINITION

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best available copy.

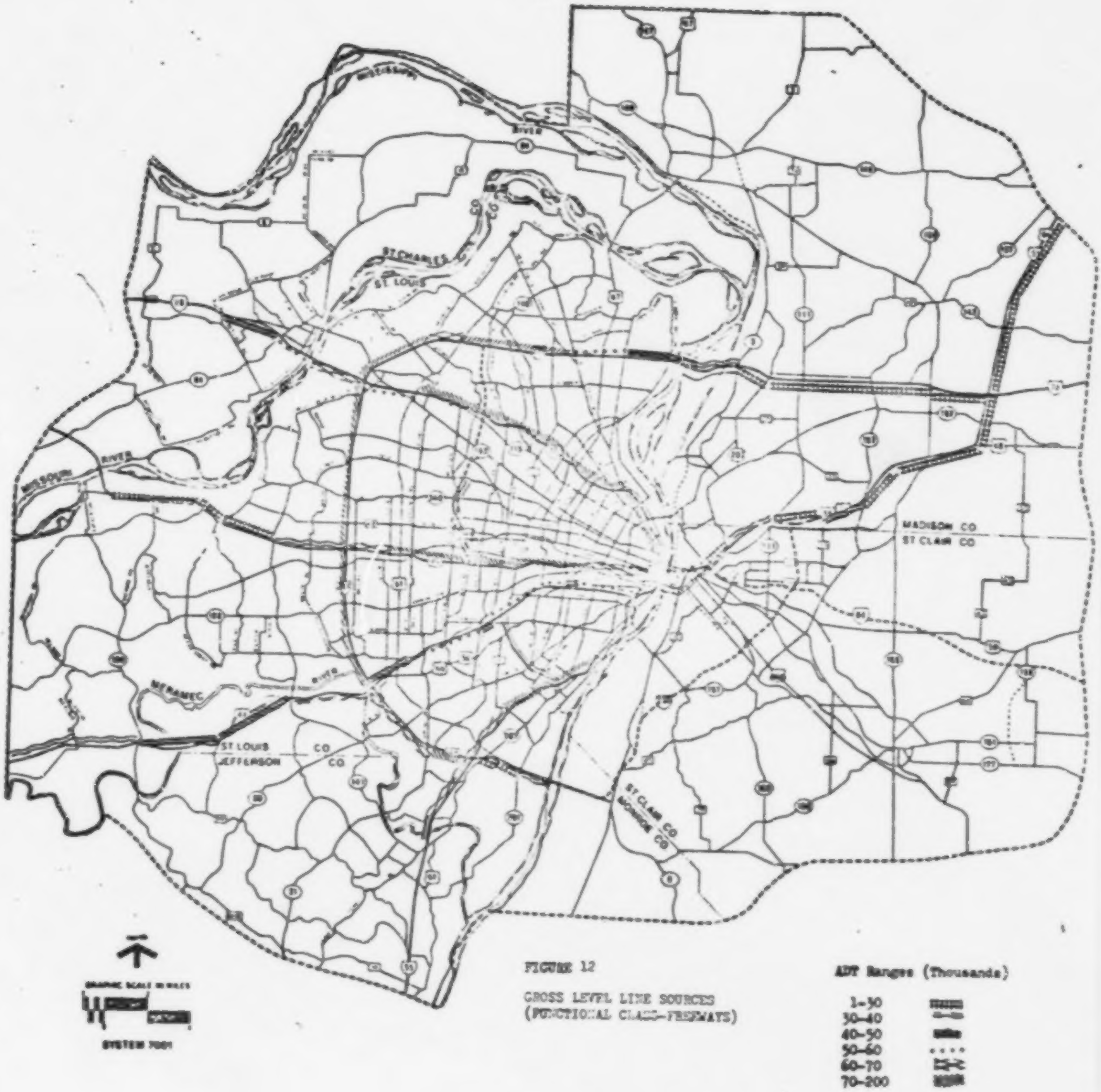

FIGURE 12

GROSS LEVEL LINE SOURCES
(FUNCTIONAL CLASS-FREEWAYS)

	ADT Ranges (Thousands)						
	1-30	30-40	40-50	50-60	60-70	70-200	Total
VMT (24 hours)	624,407	563,007	889,163	1,015,384	1,728,011	2,774,162	7,594,134
Emissions (kilo-grams/24-hr. period)							
CO	10,906	10,221	16,876	20,849	35,901	60,375	155,128
NO_x	5,809	5,133	7,929	8,701	14,747	23,163	65,482
HC	2,257	2,073	3,340	3,956	6,773	11,126	29,525
Emissions Rates (grams per vehicle-mile)							
CO	17	18	19	21	21	22	
NO_x	9	9	9	9	9	8	
HC	4	4	4	4	4	4	

TABLE 2

GROSS LEVEL LINE SOURCE EMISSIONS
(FUNCTIONAL CLASS-FREEWAYS)

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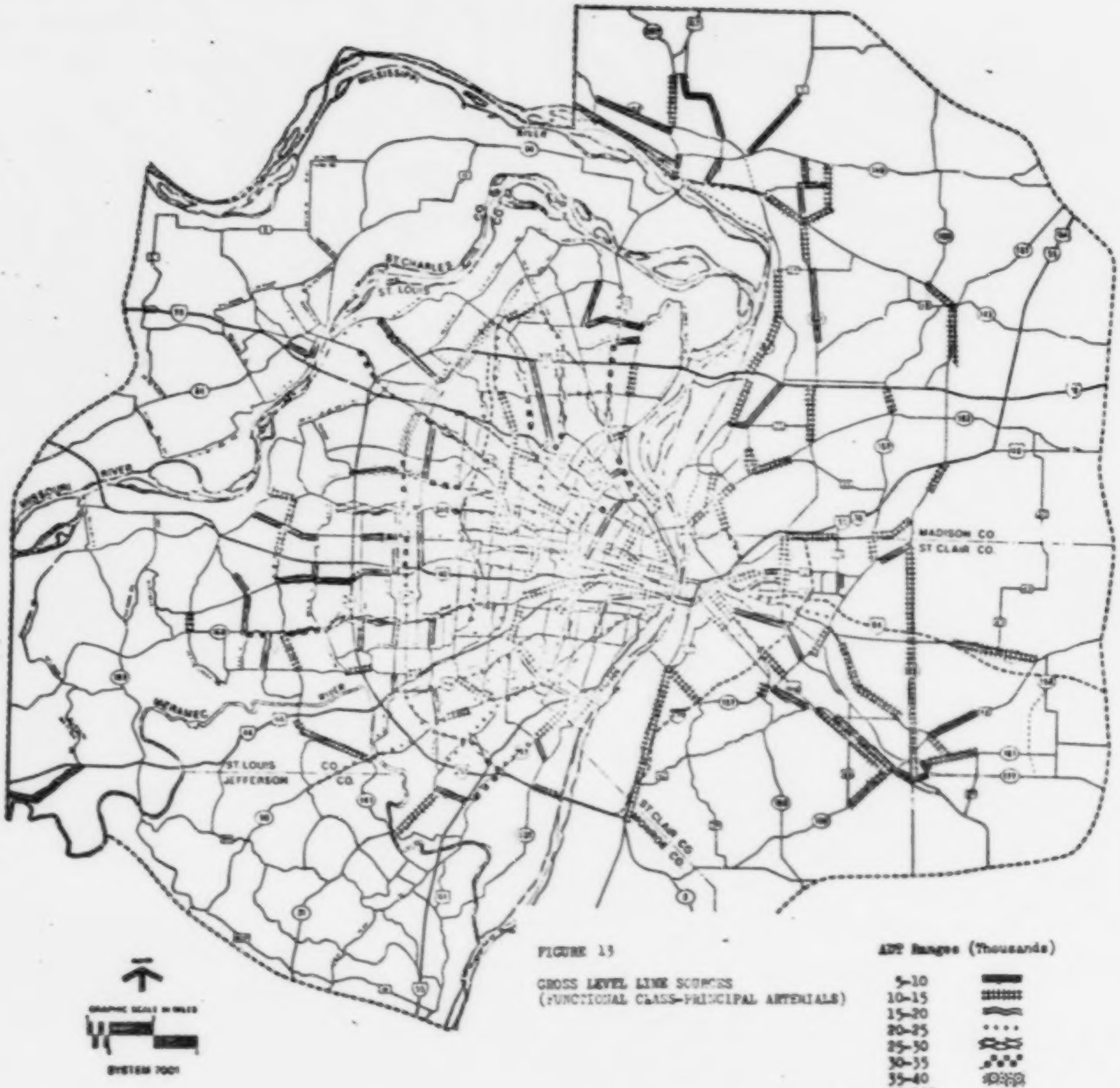

FIGURE 13

GROSS LEVEL LINE SOURCES
(FUNCTIONAL CLASS-PRINCIPAL ARTERIALS)

ADT Ranges (Thousands)	
5-10	▬
10-15	▦
15-20	≈
20-25	• • • •
25-30	⁂
30-35	∴
35-40	▩
40-100	▬

ADT Ranges (Thousands)

	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-100	Total
VMT (24 hours)	672,528	1,576,094	1,482,781	1,564,475	1,190,306	622,281	134,964	205,360	7,448,789
Emissions (kilograms/24-hour period)									
CO	21,545	52,802	51,358	53,330	45,273	26,201	5,723	8,613	264,845
NO_x	3,848	8,913	8,380	8,856	6,644	3,450	748	1,132	41,971
HC	3,325	7,982	7,610	7,973	6,384	3,498	760	1,155	38,245
Emissions Rate (grams per veh.-mile)									
CO	32	34	35	34	38	42	42	46	
NO_x	6	6	6	6	6	6	6	6	
HC	5	5	5	5	5	6	6	6	

TABLE 3

GROSS LEVEL LINE SOURCE EMISSIONS
(FUNCTIONAL CLASS-PRINCIPAL ARTERIALS)

Reproduced from
best available copy.

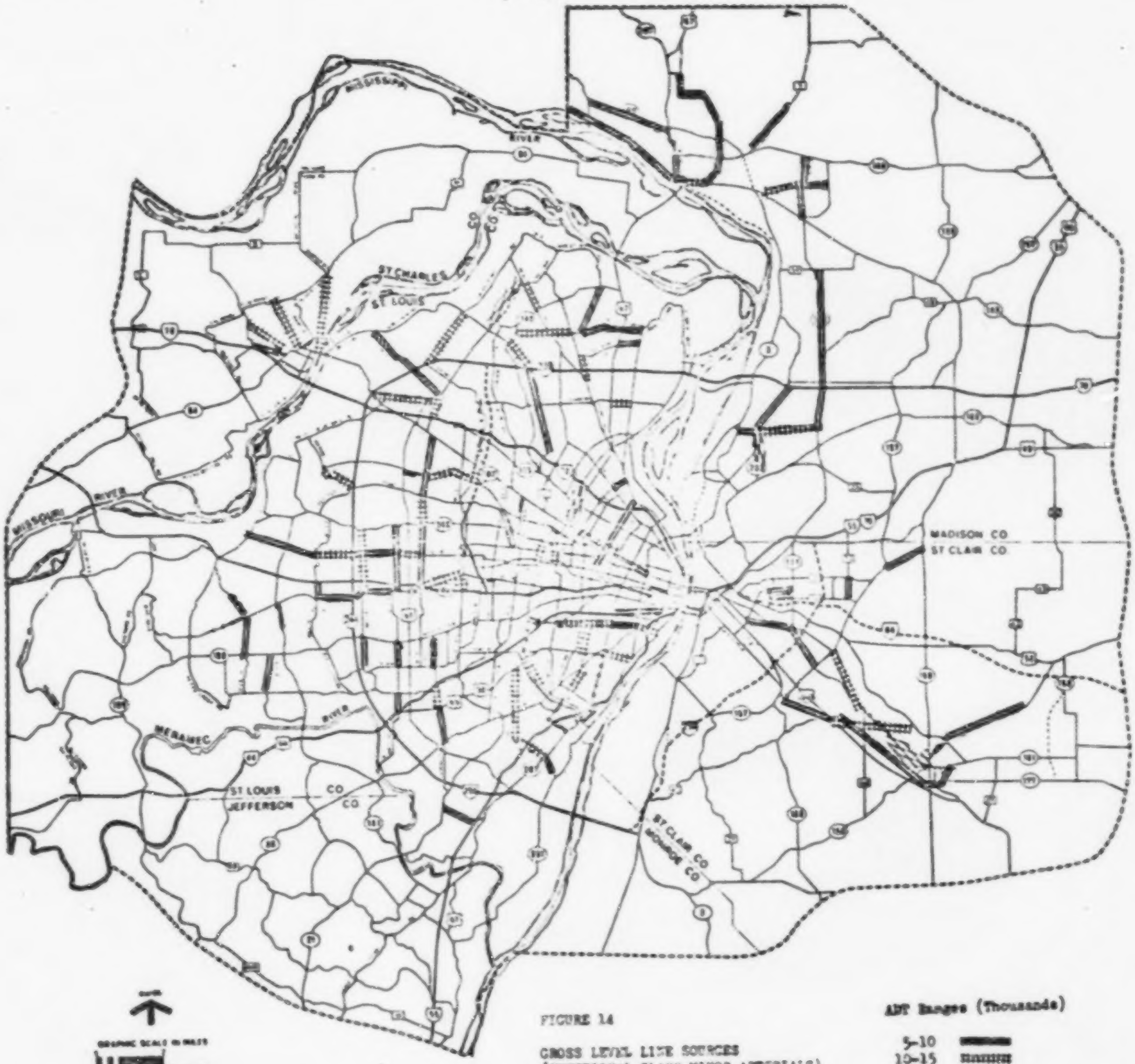

FIGURE 14

CROSS LEVEL LINE SOURCES
(FUNCTIONAL CLASS-MINOR ARTERIALS)

ADT Ranges (Thousands)

5-10	▬
10-15	▨
15-20	• • • • •
20-40	≋

ADT Ranges (Thousands)

	5-10	10-15	15-20	20-40	Total
VMT (24 hours)	612,870	594,058	319,406	191,680	1,718,014
Emissions (kilograms/24-hour period)					
CO	20,330	19,713	12,611	9,695	62,349
NO_x	3,496	3,369	1,779	1,012	9,656
HC	3,076	2,994	1,744	1,193	9,007
Emissions Rates (g/veh.-mile)					
CO	33	33	39	51	
NO_x	6	6	6	5	
HC	5	5	5	6	

TABLE 4

GROSS LEVEL LINE SOURCE EMISSIONS
(FUNCTIONAL CLASS-MINOR ARTERIALS)

due to increased flow. The NO_x rate shows some reductions in the latter ADT ranges of each class. This is apparently due to reductions in the average speed on these higher volume sets of links which operate at or near saturated levels of congestion.

C. Refined Level - Ultimate Definition of Line Sources

The most refined level of line source definition used involved classifying the links by narrow ranges of ADT and combinations of special characteristics defining their attributes. These attributes have been noted in depth in Chapters II and III. The following paragraphs show some examples of typical 24-hour graphic and tabular information which form the ultimate definition of line sources for the St. Louis Air Quality Control Region. Detailed commentary will be reserved until synthesis of information occurs in Table 17.

The initial presentation in Table 5 exhibits the basic ADT ranges used in conjunction with the various combinations of attributes. Figure 15 represents those freeway links in the various ADT ranges for which none of the attributes of special topography, capacity alterations, or sensitive land use were present. Table 6 is an emissions summary of these links from Figure 15. Further, Figure 16 depicts those freeway links in various ADT ranges for which capacity alterations were present but not special topography or sensitive land use attributes. Their emissions are summarized in Table 7. Likewise, Figure 17 depicts those freeway links in various ADT ranges for which both special topography and capacity alterations were present, but sensitive land use attributes were not. Table 8 summarizes emissions for these particular links. Figure 18 represents those freeway links, in various ADT ranges, for which the combination of attributes of special topography, capacity alterations and sensitive land use were present. Their emissions are summarized in Table 9 .

The next component series of figures and tables illustrates the most refined level of line source definition for principal arterials, using ADT ranges as noted in Table 5 . Figure 19 exhibits those principal arterial links in various ADT ranges which do not have any of the attributes of capacity alteration, progressive movement, or sensitive land use present. Table 10 summarizes emissions for these links. Figure 20 depicts those principal arterial links in various ADT ranges which had attributes of capacity alteration, but no attributes of progressive movement, or sensitive land use. Their emissions are summarized in Table 11. Further, Figure 21 illustrates those principal arterial links in various ADT ranges which have attributes of capacity alteration and progressive movement,but not sensitive land use. The emissions summary for these links is shown in Table 12. Figure 22 exhibits those principal arterial links in various ADT ranges which have all the attributes of capacity alteration, progressive movement, and sensitive land use. Their emissions are summarized in Table 13.

The final example of line source definitions is composed of minor arterials in the ADT ranges previously noted in Table 5. Figure 23 illustrates those minor arterial links in various ADT ranges which did not have any attributes of capacity alterations, progressive movement, or sensitive land use. Their emissions are summarized in Table 14. Figure 24 shows those minor arterial links in various

ADT Ranges (Thousands)	Freeways	Principal Arterials	Minor Arterials
5-10		X	X
10-15		X	X
15-20		X	X
20-25		X	
20-40			X
25-30		X	
30-35	X	X	
35-40	X	X	
40-45	X		
45-50	X		
50-55	X		
55-60	X		
60-65	X		
65-70	X		
70-200	X		
40-100		X	

TABLE 5

ADT RANGES USED FOR ULTIMATE
LINE SOURCE DEFINITION

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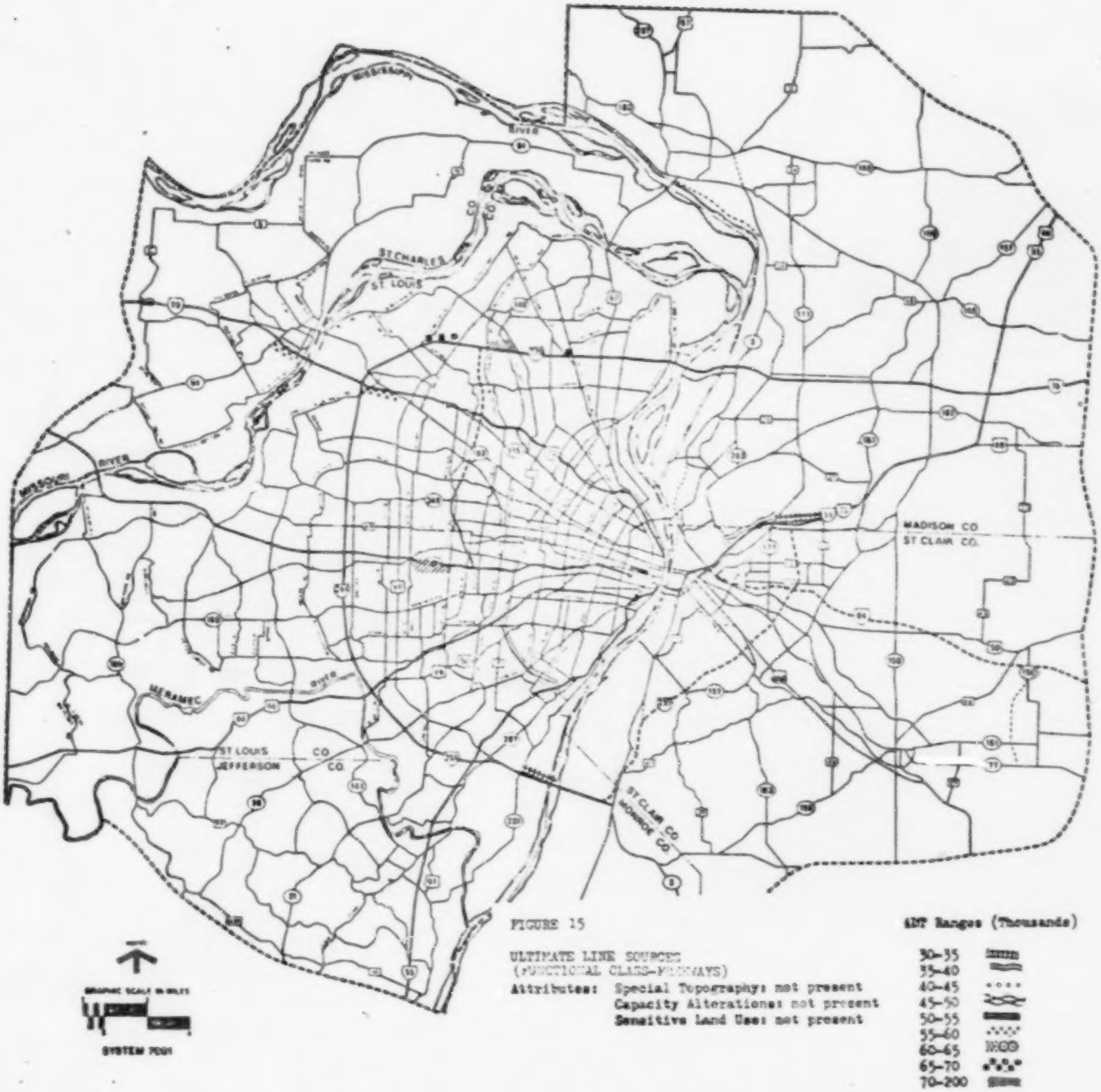

FIGURE 15

ULTIMATE LINE SOURCES
(FUNCTIONAL CLASS-FREEWAYS)

Attributes: Special Topography: not present
Capacity Alterations: not present
Sensitive Land Use: not present

ADT Ranges (Thousands)

30-35 ▤
35-40 ═
40-45 ····
45-50 ≈
50-55 ▬
55-60 ⁘
60-65 ○○○
65-70 ⁘
70-200 ▦

ADT Ranges (Thousands)

	30–35	35–40	40–45	45–50	50–55	55–60	60–65	65–70	70–200	Total
VMT (24 hours)	90,462	0	0	0	0	153,325	0	124,945	245,958	614,677
Emissions (kilograms/24-hour period)										
CO	2,697	0	0	0	0	2,984	0	6,598	13,242	25,521
NO_x	690	0	0	0	0	1,350	0.	809	1,570	4,419
HC	424	0	0	0	0	582	0	809	1,613	3,428
Emissions Rates (g/veh.-mile)										
CO	30	0	0	0	0	19	0	53	54	
NO_x	8	0	0	0	0	9	0	6	6	
HC	5	0	0	0	0	4	0	6	7	

TABLE 6

ULTIMATE LINE SOURCE EMISSIONS
(FUNCTIONAL CLASS - FREEWAYS)
Attributes: Special Topography: not present
Capacity Alterations: not present
Sensitive Land Use: not present

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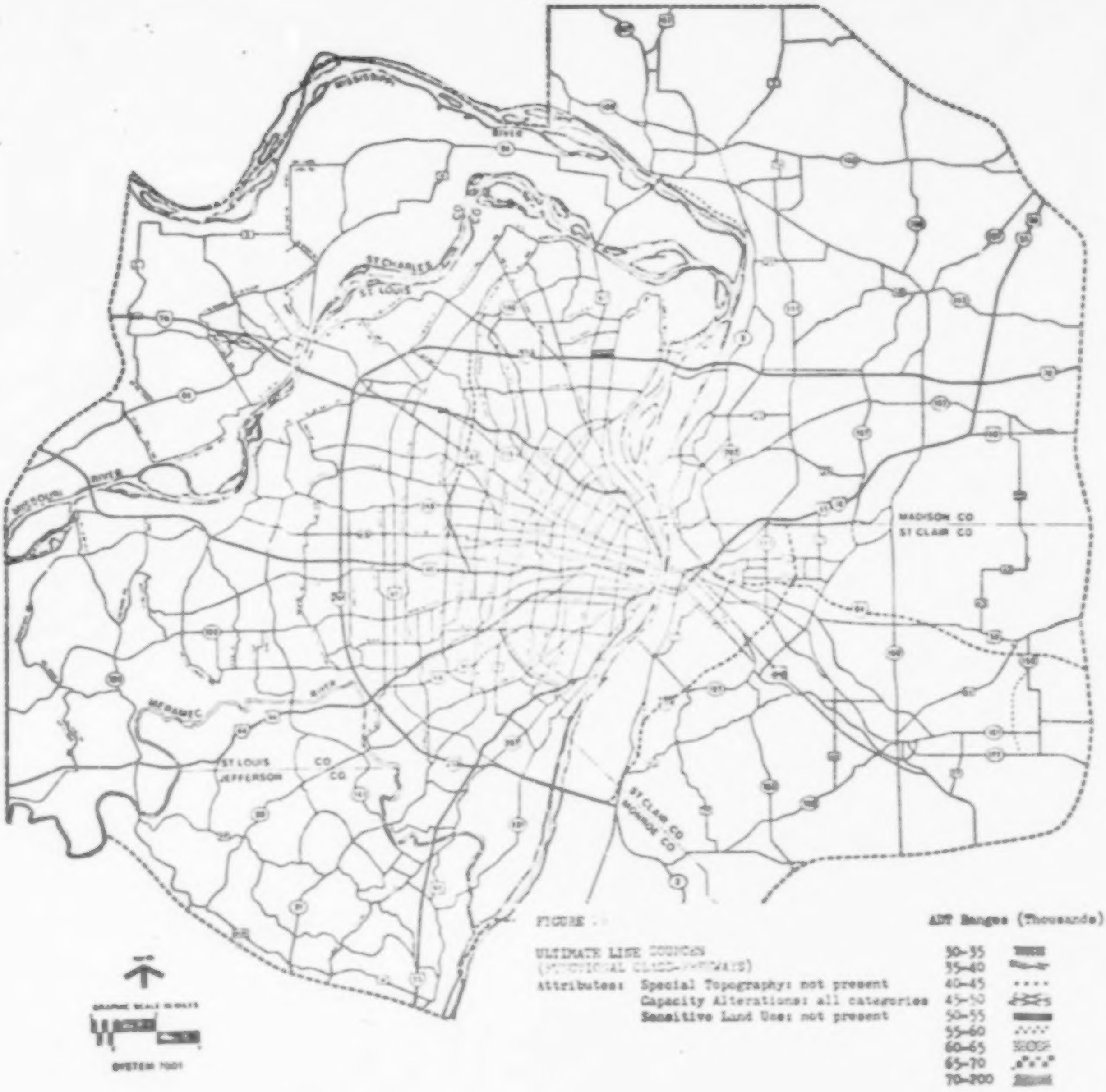

FIGURE [illegible]

ULTIMATE LINE CONTOUR
(FUNCTIONAL CLASS-FREEWAYS)

Attributes: Special Topography: not present
Capacity Alterations: all categories
Sensitive Land Use: not present

ADT Ranges (Thousands)

	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-200	Total
VMT (24 hours)	0	0	0	133,200	53,388	0	0	0	0	186,588
Emissions (kilograms/24-hour period)										
CO	0	0	0	2,520	355	0	0	0	0	2,875
NO_x	0	0	0	1,189	322	0	0	0	0	1,511
HC	0	0	0	500	46	0	0	0	0	546
Emissions Rates (g/veh.-mile)										
CO	0	0	0	19	46	0	0	0	0	
NO_x	0	0	0	9	7	0	0	0	0	
HC	0	0	0	4	6	0	0	0	0	

TABLE 7

ULTIMATE LINE SOURCE EMISSIONS
(FUNCTIONAL CLASS - FREEWAYS)

Attributes: Special Topography: not present
Capacity Alterations: all categories
Sensitive Land Use: not present

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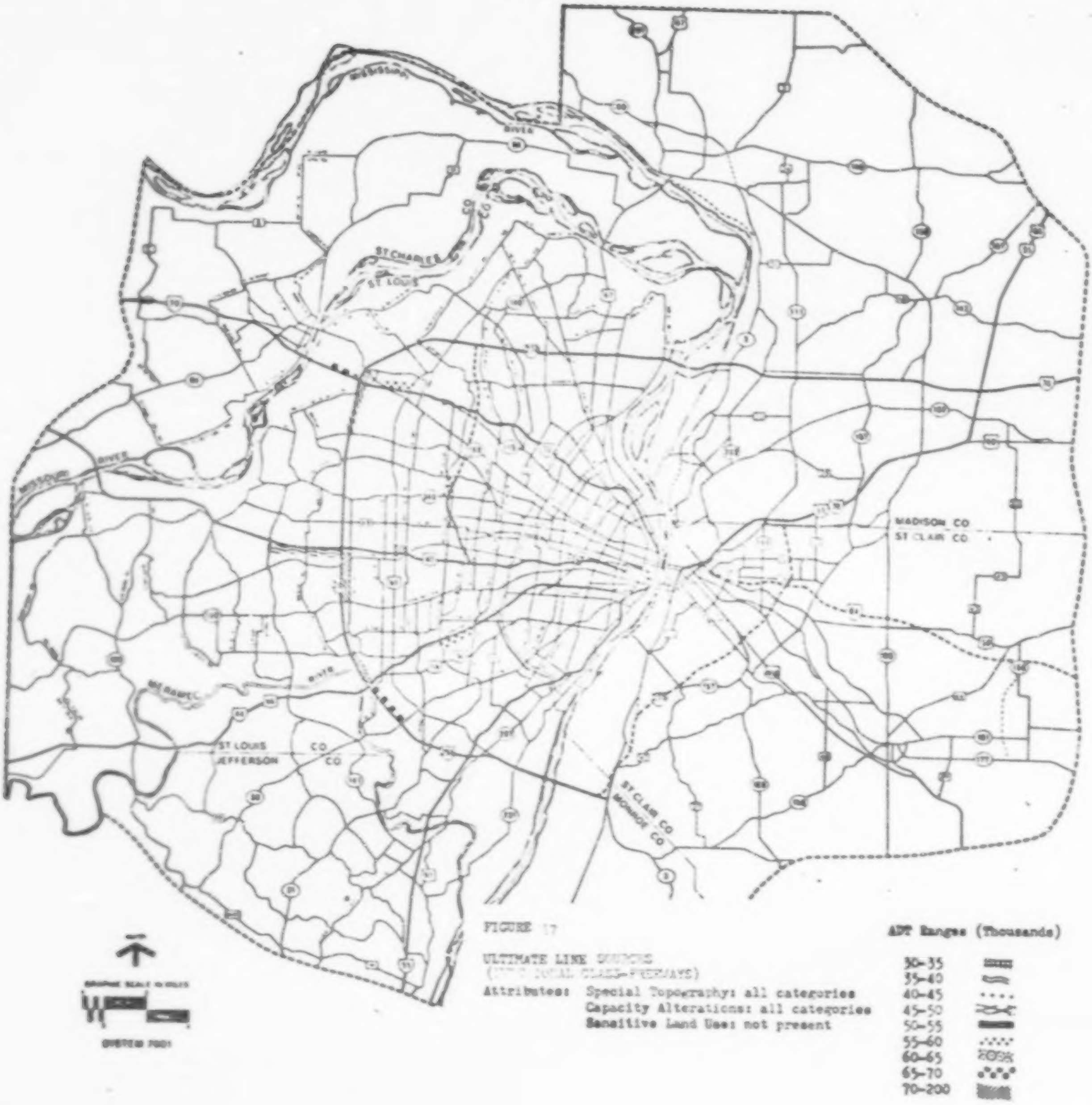

FIGURE 17

ULTIMATE LINE SOURCES
(FUNCTIONAL CLASS-FREEWAYS)

Attributes: Special Topography: all categories
Capacity Alterations: all categories
Sensitive Land Use: not present

ADT Ranges (Thousands)

	30–35	35–40	40–45	45–50	50–55	55–60	60–65	65–70	70–200	Total
VMT (24 hours)	29,475	122,582	22,373	0	0	180,470	16,210	256,155	320,842	948,107
Emissions (kilograms/24-hour period)										
CO	532	2,247	558	0	0	3,648	410	10,295	16,091	33,781
NO_x	269	1,112	172	0	0	1,562	124	1,876	2,084	7,199
HC	108	453	96	0	0	697	70	1,400	2,016	4,840
Emissions Rates (g/veh.-mile)										
CO	18	18	25	0	0	20	25	40	50	
NO_x	9	9	8	0	0	9	8	7	6	
HC	4	4	4	0	0	4	4	5	6	

TABLE 8

ULTIMATE LINE SOURCE EMISSIONS
(FUNCTIONAL CLASS-FREEWAYS)
Attributes: Special Topography: all categories
Capacity Alterations: all categories
Sensitive Land Use: not present

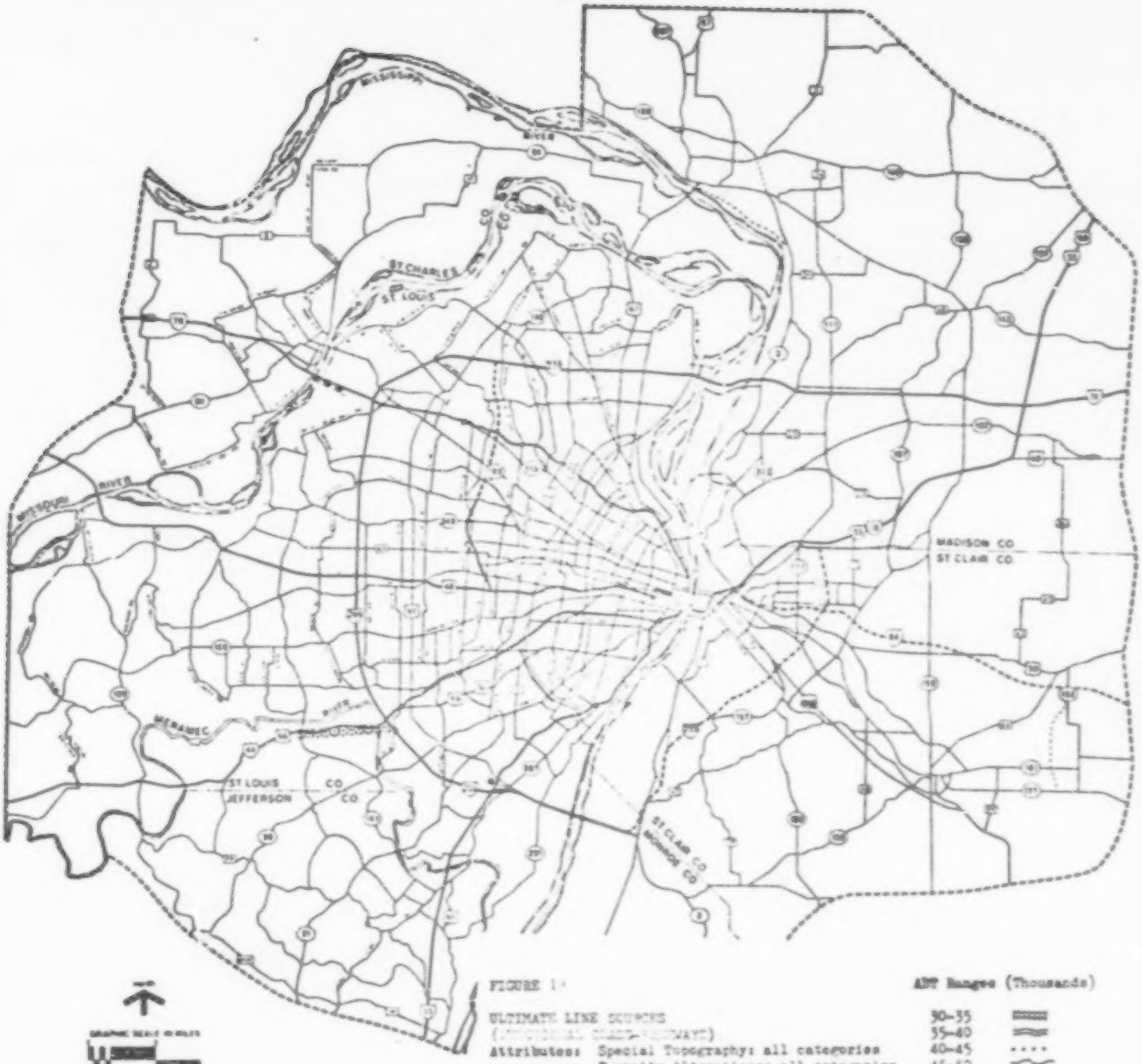

FIGURE 1

ULTIMATE LINE SOURCES
([illegible])
Attributes: Special Topography: all categories
Capacity Alterations: all categories
Sensitive Land Use: all categories

ADT Ranges (Thousands)

30-35	▤
35-40	═
40-45	· · · ·
45-50	≈
50-55	▬
55-60	·˙·˙· 60-65 ▨
65-70	°·°·°
70-200	▨

ADT Ranges (Thousands)

	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-200	Total
VMT (24 hours)	0	17,589	0	0	0	11,158	267,212	138,132	36,184	470,275
Emissions (kilograms/24-hour period)										
CO	0	666	0	0	0	551	5,883	4,572	972	12,644
NO_x	0	126	0	0	0	71	2,293	1,008	269	3,767
HC	0	94	0	0	0	70	1,071	683	163	2,081
Emissions Rates (g/veh.-mile)										
CO	0	38	0	0	0	49	22	33	27	
NO_x	0	7	0	0	0	6	9	7	7	
HC	0	5	0	0	0	6	4	5	4	

TABLE 9

ULTIMATE LINE SOURCE EMISSIONS
(FUNCTIONAL CLASS-FREEWAYS)
Attributes: Special Topography: all categories
Capacity Alterations: all categories
Sensitive Land Use: all categories

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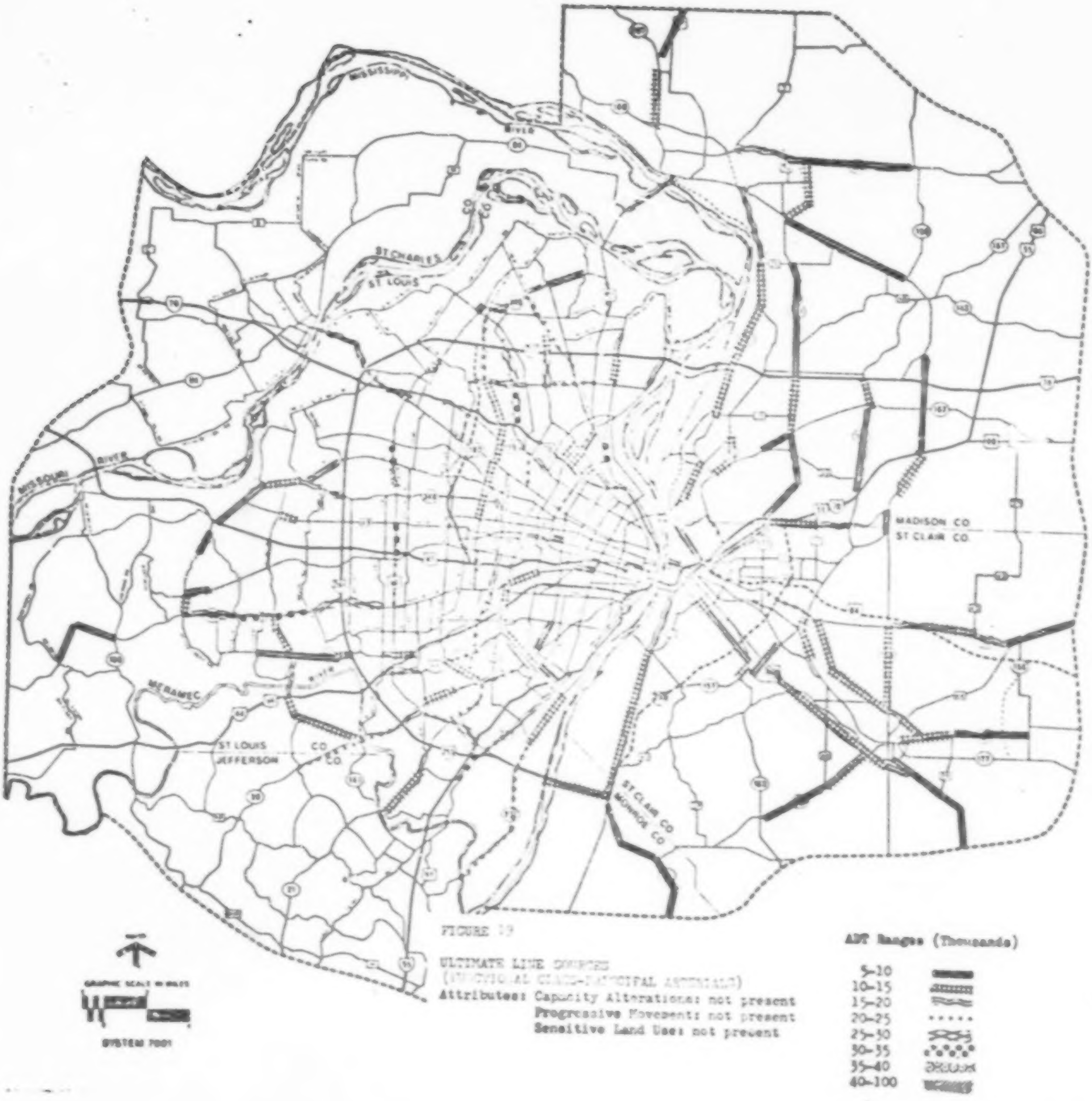

FIGURE 19

ULTIMATE LINE SOURCES
(FUNCTIONAL CLASS-PRINCIPAL ARTERIALS)
Attributes: Capacity Alterations: not present
Progressive Movement: not present
Sensitive Land Use: not present

ADT Ranges (Thousands)

	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-100	Total
VMT (24 hours)	440,668	921,497	643,503	921,216	368,674	246,413	23,179	110,994	3,676,144
Emissions (Kilo-grams/24-hour period)									
CO	14,094	30,530	21,804	31,373	14,326	12,140	728	4,974	129,969
NO_x	2,522	5,234	3,655	5,237	2,057	1,341	133	607	20,786
HC	2,178	4,634	3,267	4,680	1,995	1,500	113	645	19,012
Emissions Rate (grams per veh.-mile)									
CO	32	33	34	34	39	49	31	45	
NO_x	6	6	6	6	6	5	6	5	
HC	5	5	5	5	5	6	5	6	

TABLE 10

ULTIMATE LINE SOURCE EMISSIONS
(FUNCTIONAL CLASS-PRINCIPAL ARTERIALS)
Attributes: Capacity Alterations: not present
Progressive Movement: not present
Sensitive Land Use: not present

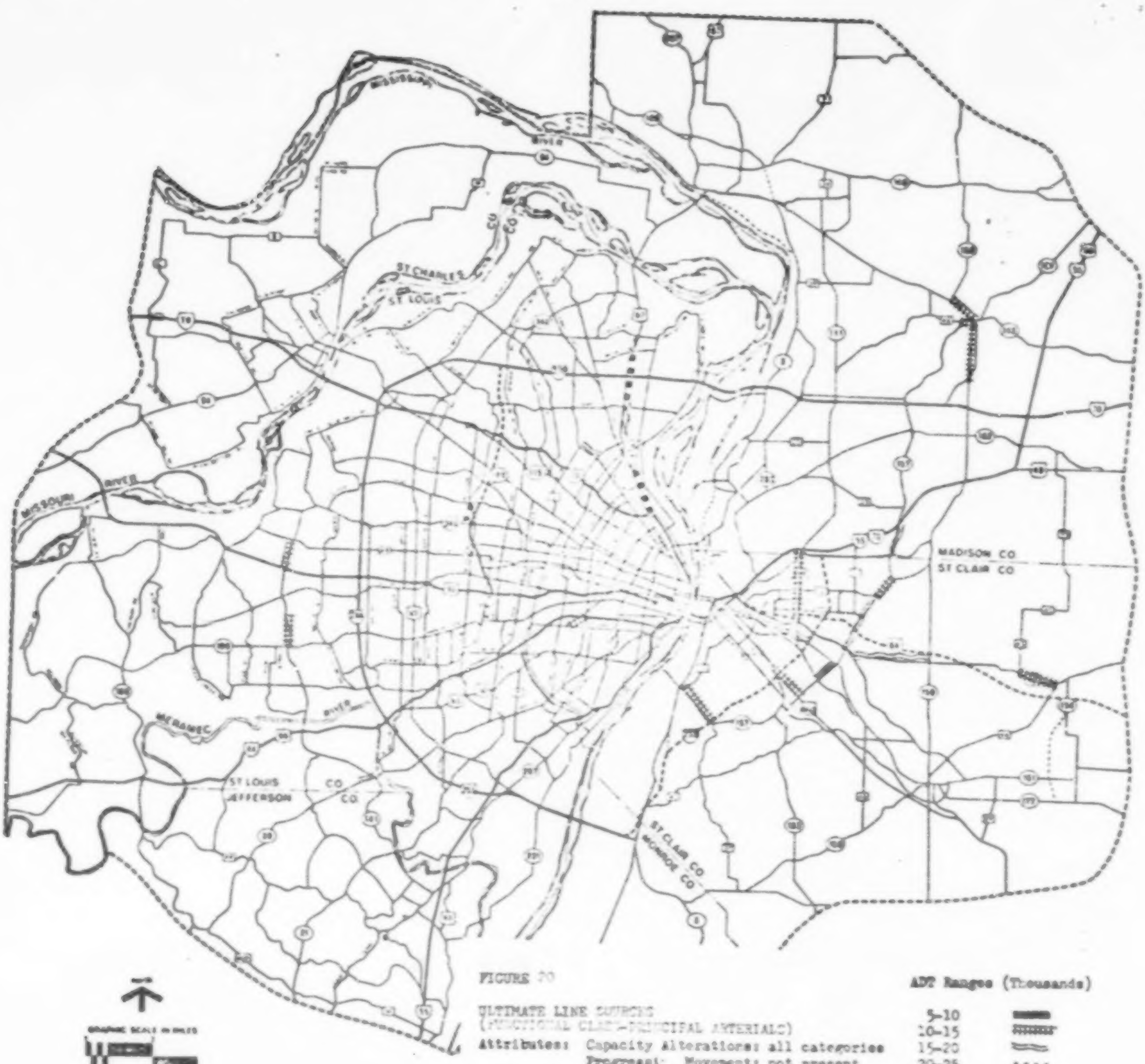

FIGURE 20

ULTIMATE LINE SOURCES
(FUNCTIONAL CLASS-PRINCIPAL ARTERIALS)

Attributes: Capacity Alterations: all categories
Progressive Movement: not present
Sensitive Land Use: not present

ADT Ranges (Thousands)	
5-10	▬
10-15	▤
15-20	═
20-25	• • • •
25-30	≈
30-35	∴
35-40	○
40-100	▨

ADT ranges which have attributes of capacity alteration, but no progressive movement or sensitive land use. Emissions from the link subset are summarized in Table 15. Figure 25 depicts those minor arterial links in various ADT ranges which have attributes of capacity alteration and progressive movement, but no sensitive land use attributes. Table 16 summarizes these particular emissions. Finally, there are no minor arterial links in various ADT ranges which have all the attributes of capacity alteration, progressive movement, and sensitive land use. The synthesis of all possible component attribute groups over all functional classes represents the most refined and accurate level of line source definition for the St. Louis Air Quality Control Region on the basis of current network data. Discussion of the implications of this synthesis will occur in the immediately following section.

D. Synthesis of Line Source Information

The synthesis of 24-hour detailed definition and description of line source information provided by NETSEN, and their resulting emissions computations from SAPOLLUT is shown in Table 17. The aggregate network of line sources encompasses approximately 1,370 miles of roadway, with a total of nearly 17 million vehicle miles of travel daily. Approximately 45% of this VMT exposure occurs on freeways, 44% on principal arterials, and the remaining 11% on minor arterials. In terms of mileage, 195 miles is composed of freeway line sources, representing the freeway corridors of the region, and the principal and minor arterials comprise the remaining 1,175 miles of line sources. The aggregate 24-hour emissions are 482,322 kg. of CO, 117,109 kg. of NO_x and 76,777 kg. of HC. A component analysis in Table 18 shows that

ADT Ranges (Thousands)

	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-100	Total
VMT (24 hours)	25,200	160,958	112,732	157,693	82,300	88,483	10,950	0	638,316
Emissions (kilograms/24-hour period)									
CO	829	5,464	4,191	5,994	3,166	3,408	362	0	23,414
NO_x	143	906	627	870	460	493	62	0	3,561
HC	127	822	599	850	443	478	55	0	3,374
Emission Rate (grams per veh.-mile)									
CO	33	34	37	38	38	39	33	0	
NO_x	6	6	6	6	6	6	6	0	
HC	5	5	5	5	5	5	5	0	

TABLE 11

ULTIMATE LINE SOURCE EMISSIONS
(FUNCTIONAL CLASS-PRINCIPAL ARTERIALS)
Attributes: Capacity Alterations: **all categories**
Progressive Movement: not present
Sensitive Land Use: not present

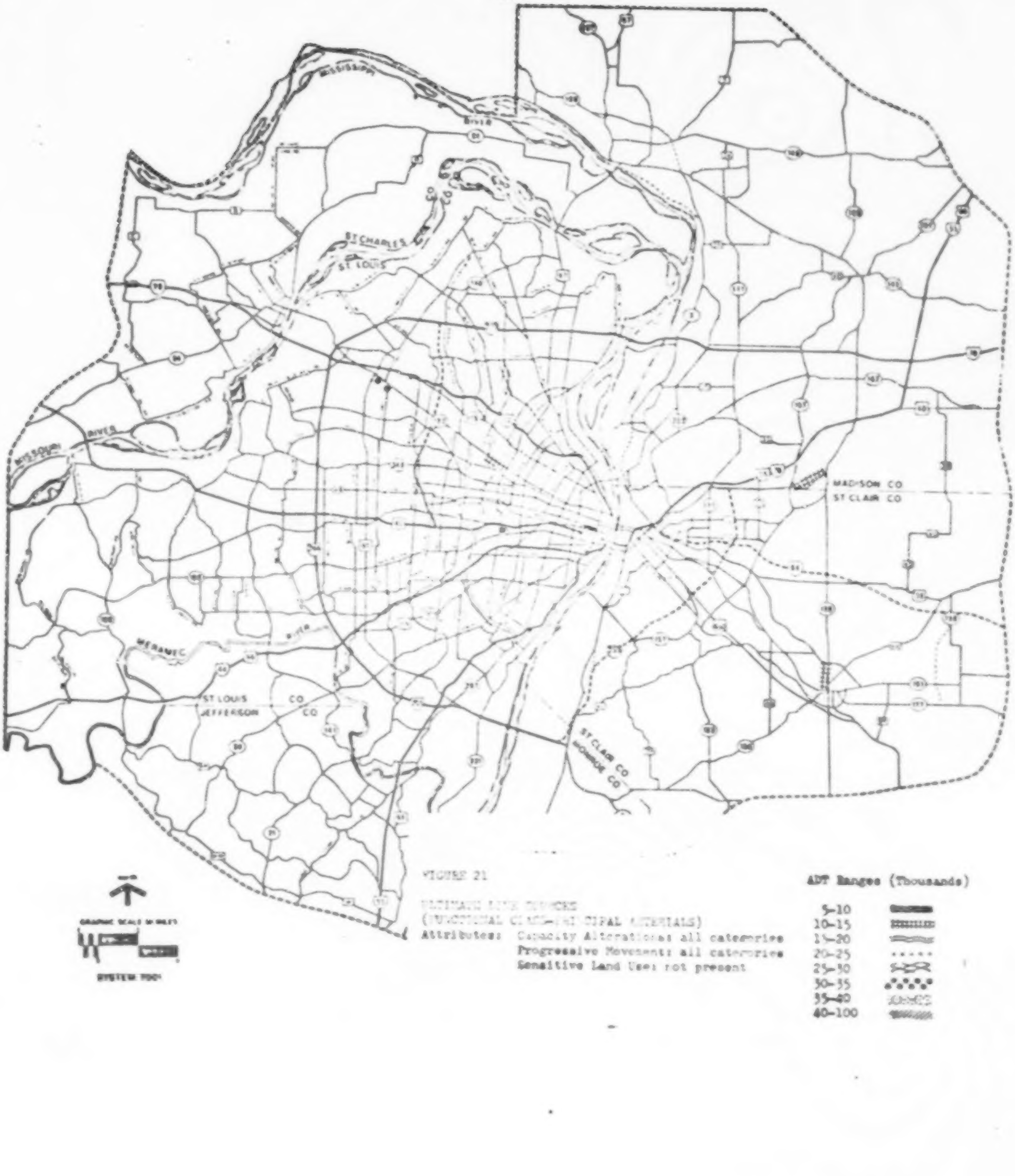

FIGURE 21

ULTIMATE LINK CHANGES
(FUNCTIONAL CLASS—PRINCIPAL ARTERIALS)
Attributes: Capacity Alterations: all categories
Progressive Movement: all categories
Sensitive Land Use: not present

ADT Ranges (Thousands)

	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-100	Total
VMT (24 hours)	0	38,160	17,780	0	46,867	40,470	0	.0	143,277
Emissions (kilograms/24-hour period)									
CO	0	1,245	841	0	1,748	1,624	0	0	5,458
NO_x	0	217	96	0	261	225	0	0	799
HC	0	191	106	0	250	223	0	0	770
Emissions Rate (grams per veh.-mile)									
CO	0	33	47	0	37	40	0	0	
NO_x	0	6	5	0	6	6	0	0	
HC	0	5	6	0	5	5	0	0	

TABLE 12

ULTIMATE LINE SOURCE EMISSIONS
(FUNCTIONAL CLASS-PRINCIPAL ARTERIALS)
Attributes: Capacity Alterations: all categories
Progressive Movement: all categories
Sensitive Land Use: not present

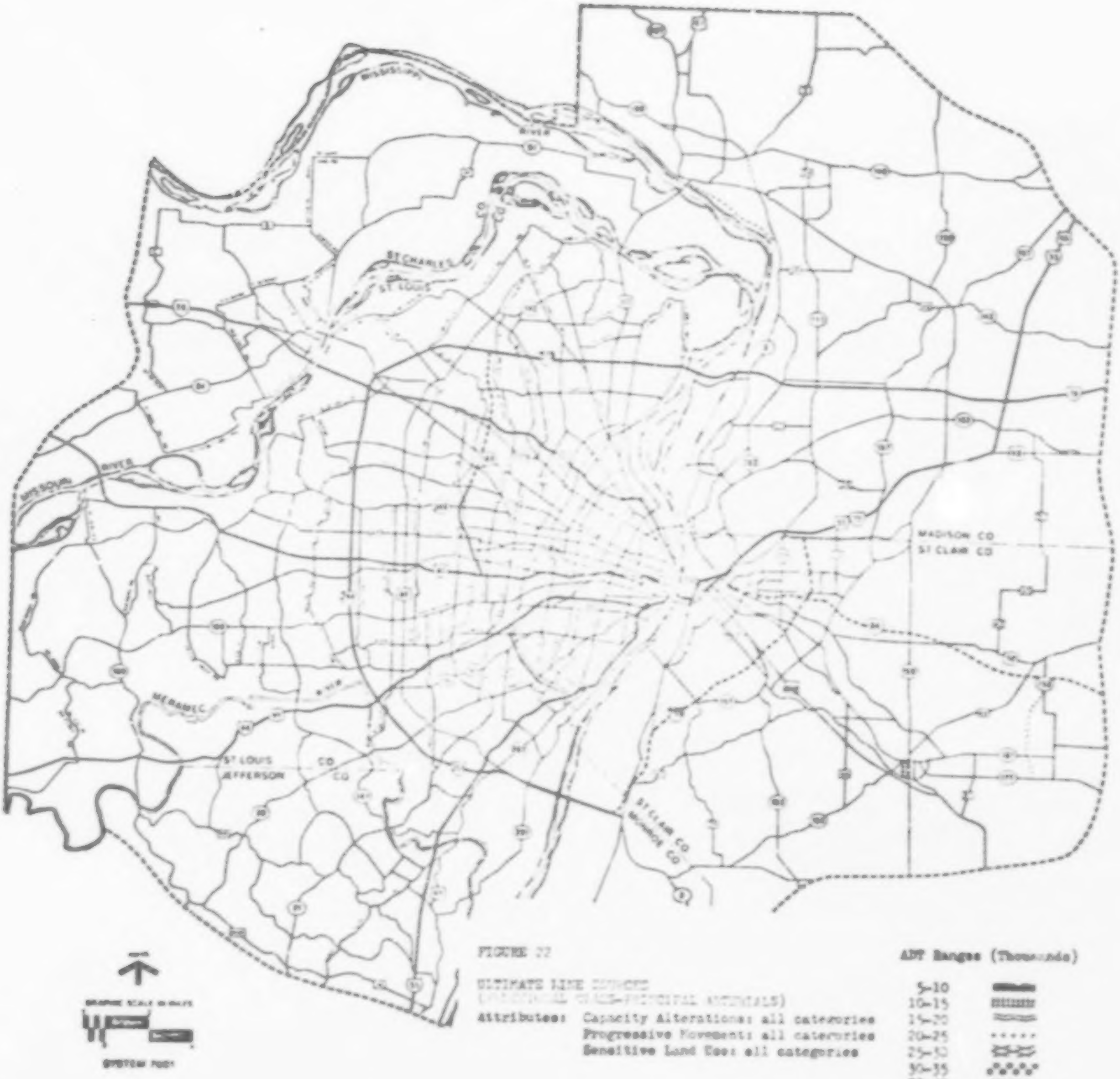

FIGURE 22

ULTIMATE LINE IMPACTS
(FUNCTIONAL CLASS—PRINCIPAL ARTERIALS)

Attributes: Capacity Alterations: all categories
Progressive Movement: all categories
Sensitive Land Use: all categories

ADT Ranges (Thousands)

	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-100	Total
VMT (24 hours)	0	8,240	0	0	0	0	0	0	8,240
Emissions (kilo-grams/24-hour period)									
CO	0	277	0	0	0	0	0	0	277
NO_x	0	46	0	0	0	0	0	0	46
HC	0	42	0	0	0	0	0	0	42
Emissions Rate (grams per veh.-mile)									
CO	0	34	0	0	0	0	0	0	
NO_x	0	6	0	0	0	0	0	0	
HC	0	5	0	0	0	0	0	0	

TABLE 13

ULTIMATE LINE SOURCE EMISSIONS
(FUNCTIONAL CLASS-PRINCIPAL ARTERIALS)
Attributes: Capacity Alterations: all categories
Progressive Movement: all categories
Sensitive Land Use: all categories

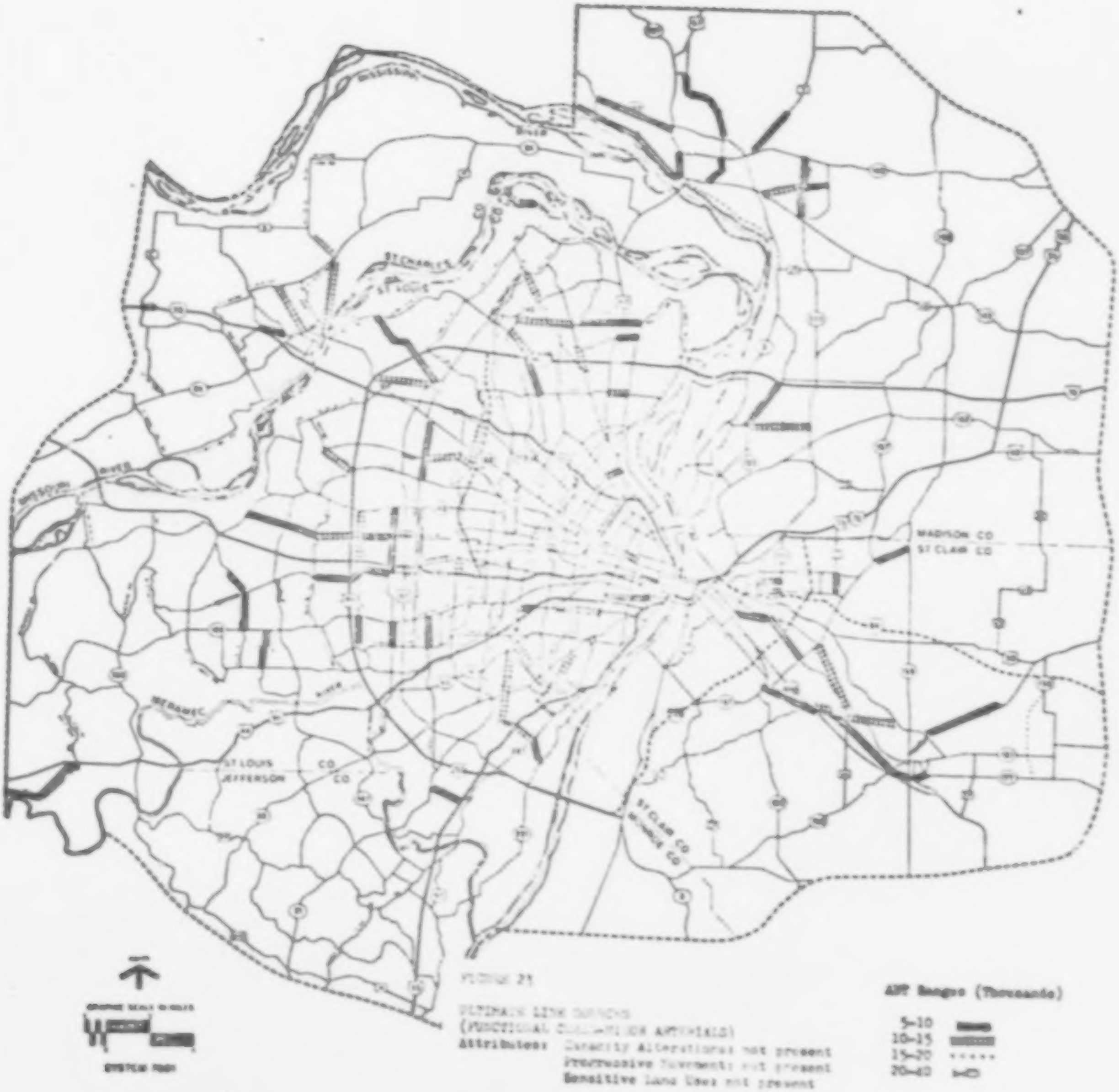

FIGURE 21

ULTIMATE LINK CHANGES
(FUNCTIONAL CLASSIFICATION ARTERIALS)
Attributes: Capacity Alterations: not present
Progressive Movement: not present
Sensitive Land Uses: not present

	ADT Ranges (Thousands)				
	5-10	10-15	15-20	20-40	Total
VMT (24 hours)	539,917	488,099	218,731	90,525	1,377,272
Emissions (kilograms/24-hour period)					
CO	18,020	16,144	9,043	4,357	47,564
NO_x	3,078	2,772	1,216	488	7,554
HC	2,717	2,455	1,218	547	6,937
Emissions Rates (g/veh.-mile)					
CO	33	33	41	48	
NO_x	6	6	6	5	
HC	5	5	6	6	

TABLE 14

ULTIMATE LINE SOURCE EMISSIONS
(FUNCTIONAL CLASS-MINOR ARTERIALS)

Attributes: Capacity Alterations: not present
Progressive Movement: not present
Sensitive Land Use: not present

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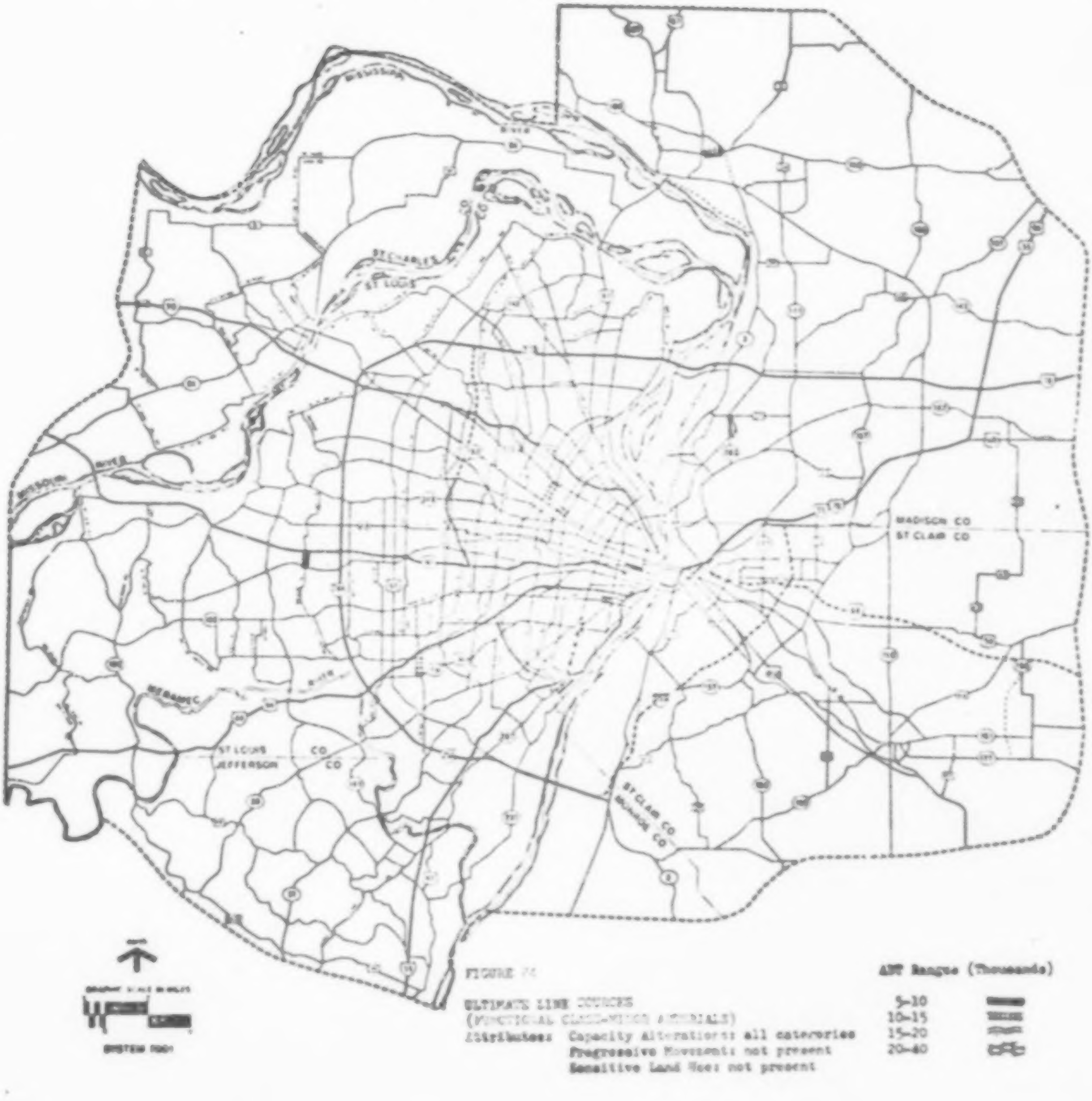

FIGURE 74

ULTIMATE LINE SOURCES
(FUNCTIONAL CLASS—MINOR ARTERIALS)
Attributes: Capacity Alterations: all categories
Progressive Movement: not present
Sensitive Land Use: not present

ADT Ranges (Thousands)	
5-10	▬
10-15	▤
15-20	═
20-40	▭

ADT Ranges (Thousands)

	5-10	10-15	15-20	20-40	Total
VMT (24 hours)	18,032	24,161	81,595	33,458	157,246
Emissions (kilograms/24-hour period)					
CO	575	839	2,944	1,985	6,343
NO_x	103	135	455	175	868
HC	89	125	430	227	871
Emissions Rates (g/veh.-mile)					
CO	32	35	36	59	
NO_x	6	6	6	5	
HC	5	5	5	7	

TABLE 15

ULTIMATE LINE SOURCE EMISSIONS
(FUNCTIONAL CLASS-MINOR ARTERIALS)

Attributes: Capacity Alterations: all categories
Progressive Movement: not present
Sensitive Land Use: not present

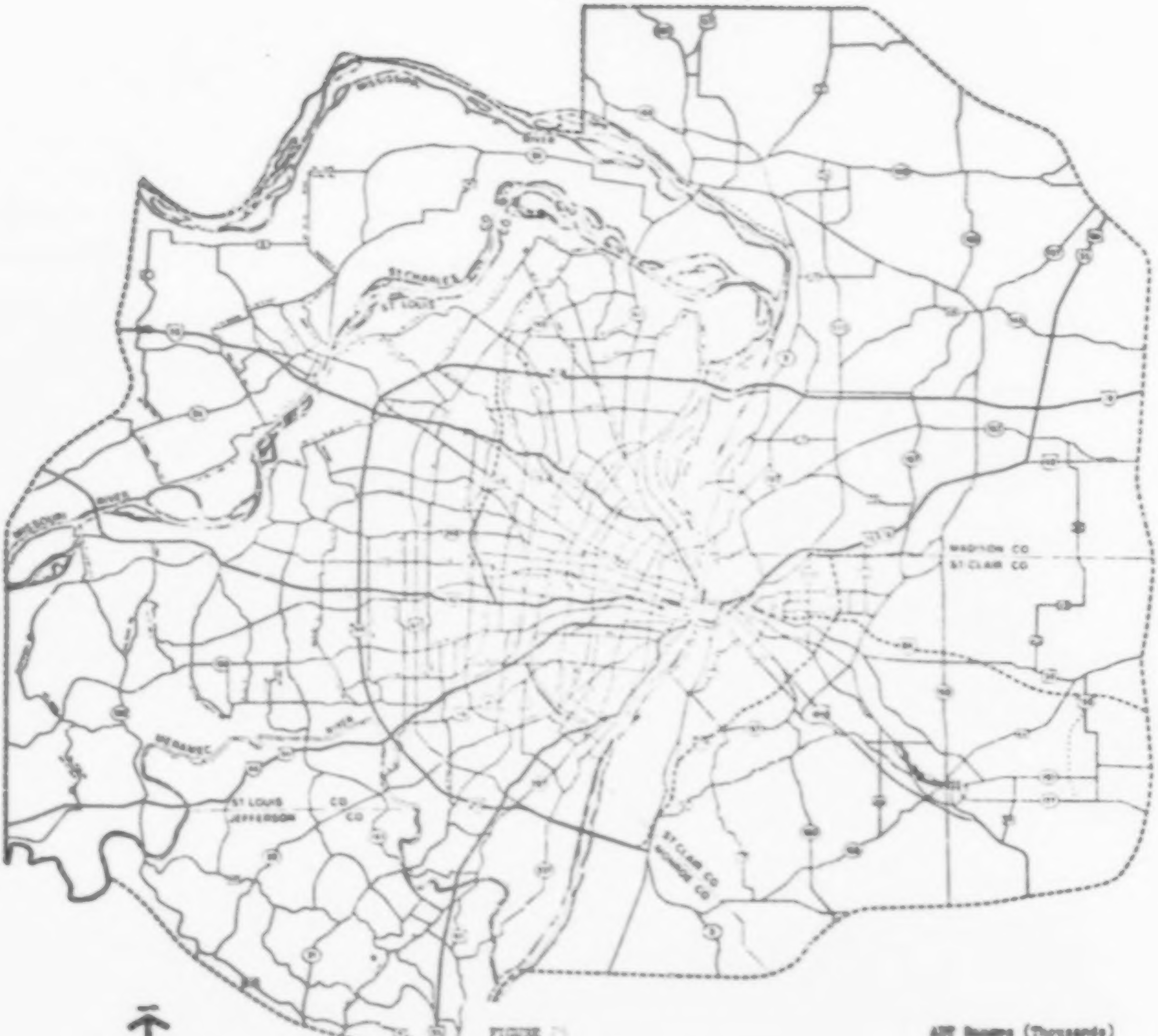

FIGURE [illegible]

ULTIMATE LINE OUTPUT
(FUNCTIONAL CLASS-MINOR ARTERIALS)
Attributes: Capacity Alterations: all categories
Progressive Movements: all categories
Sensitive Land Use: not present

ADT Ranges (Thousands)	
5-10	▬
10-15	▨
15-20	≡
20-40	≈

ADT Ranges (Thousands)

	5-10	10-15	15-20	20-40	Total
VMT (24 hours)	0	16,947	19,080	61,305	97,332
Emissions (kilograms/24-hour period)					
CO	0	622	624	2,935	4,181
NO	0	93	108	315	516
HC	0	90	96	373	559
Emissions Rates (g/veh.-mile)					
CO	0	37	33	48	
NO	0	6	6	5	
HC	0	5	5	6	

TABLE 16

ULTIMATE LINE SOURCE EMISSIONS
(FUNCTIONAL CLASS-MINOR ARTERIALS)

Attributes: Capacity Alterations: all categories
Progressive Movement: all categories
Sensitive Land Use: not present

freeway line sources consistently contribute 30-60% to totals in all emission types, with typically 50% of total contribution emanating from arterial sources, and typically near 12% being contributed from minor arterial operations. These percentages correlate closely with the logic of discussion of emission stimuli of average speed and VMT referred to in Chapter I, and component analytic discussions earlier in this immediate chapter. The average rates are aggregates over all ADT ranges considered in each of the specific functional classes under study. They show a disturbing stability across all functional classes, essentially due to the aggregation and averaging of specific V/C, average speed and VMT ranges such as those displayed in Tables 6 through 16. The research team feels that more meaningful and accurate rates exist at the dissaggregate levels such as those shown in Tables 6 through 16 where rates specific to ADT ranges for particular components of the line sources containing specific attributes are exhibited.

E. Related Processing Costs

The traffic emissions software system developed herein is a series of eight basic programs coupled to a variable number of utility programs. Two of the eight basic programs are run only once. As such, this discussion will deal only with the remaining six involved in software processing with SAPOLLUT. It is theoretically possible to make 95 separate runs of the system under one batch job, however, only four runs were made in one job for the duration of the project, in order to facilitate turn around time. A threshhold fixed cost figure for one run through the system which produced emissions on only line link would be approximately $3.00. This cost represents the system overhead and individual

Functional Class

	Freeway	Principal Arterials	Minor Arterials	Totals
Total VMT* (24 hours)	7,594,134	7,448,789	1,718,014	16,760,937
Total Emissions (kilograms/24-hour period)				
CO	155,128	264,845	62,349	482,322
NO_x	65,482	41,971	9,656	117,109
HC	29,525	38,245	9,007	76,777
Average Rate of Emissions (g./vehicle-mile)				
CO	20	36	36	
NO_x	9	6	6	
HC	4	5	5	

*For all links with volumes reported.

TABLE 17

SUMMARY OF ULTIMATE LINE SOURCE EMISSIONS INFORMATION

Percent Contribution	Freeway	Principal Arterials	Minor Arterials	Total
CO	32%	55%	13%	100%
NO_x	56%	36%	8%	100%
HC	38%	50%	12%	100%

TABLE 18

PERCENTAGE OF TOTAL EMISSIONS
CONTRIBUTED BY FUNCTIONAL
CLASS OF LINE SOURCE

program overhead costs. Due to the rather large number of combinations of link attributes which may be tested for, results of using the system on the St. Louis Air Quality Control Region yield a typical maximum cost for one pass of $8.00, with an average cost of $5 to $6. Table 19 illustrates a typical run of the system showing time requirement, percentage of total time, and the amount of main core storage required for each program. It is interesting to note that SAPOLLUT required only 34.5% of all Central Processing Unit (CPU) time. The cost of the run is computed on the rate shown, and charges for lines printed (approximately $1 per run) should be added to the CPU time cost. If four or more passes through the system are made, which is typical of the operating rationale used in the performance of the research on the St. Louis Air Quality Control Region, the cost drops to $6.30 due to the spreading of overhead costs over several runs. It is felt this cost figure is quite tolerable, given the level of detail possible for examining the network, and the nominal number of runs required to synthesize information over all functional highway classes. All figures are for an IBM S/360 Model 65 machine.

F. Limited Sensitivity Analysis

Limited amount of sensitivity analyses were performed subsequent to the definition of line sources, to examine gross changes in the supply of highway facilities and resultant alterations of traffic flow and emissions. Two separate analyses relating to 24-hour periods were performed,

Program	CPU* Time	%	Core Required**
NETSEN	8.59	20.7	60
RUMMY	1.87	4.5	46
BUILDHR	4.25	10.2	82
PRINTHR	7.60	18.3	40
HRMOD	1.82	4.4	42
SAPOLLUT	14.35	34.5	60
MISC. UTILITIES	3.06	7.4	34
TOTALS	41.54	100.0	

*Central Processing Unit, in seconds
**in K's (1024 bytes)
***All Freeways, 145 links

TABLE 19

COST SUMMARY FOR TYPICAL
SOFTWARE SYSTEM RUN***

typical of near-term alteration of emissions estimates which might occur as typical modification of corridor facilities occurs in one case, requiring the placement of total corridor loads onto other corridors in the region during construction alterations. In the second case, a badly needed distributor facility is completed, as highway planning is brought progressively to the implementation and completion phase, yielding resulting diversion of presently congested crosstown flows onto the new high-type design facility.

The first analysis was the examination of emissions performance resulting from the deletion of availability of a freeway corridor and the resultant loading of the displaced traffic onto two adjacent freeways. This was performed through deletion of I-44 from I-55 to I-244. An average ADT was taken for I-44 and half of this was loaded onto each link of I-55 from I-44 to I-244 and the remaining half onto each link of U.S. 40 from I-55 to I-244. Figure 26 shows the location of these three freeways. Table 20 summarizes original VMT's and emissions on each freeway and their aggregate. It should be noted that because of limitations in FHWA Battery program BUILDHR, only a maximum ADT of 99,999 can be used. Therefore, since some links on U.S. 40 are either currently near or over 100,000 ADT, or would exceed 100,000

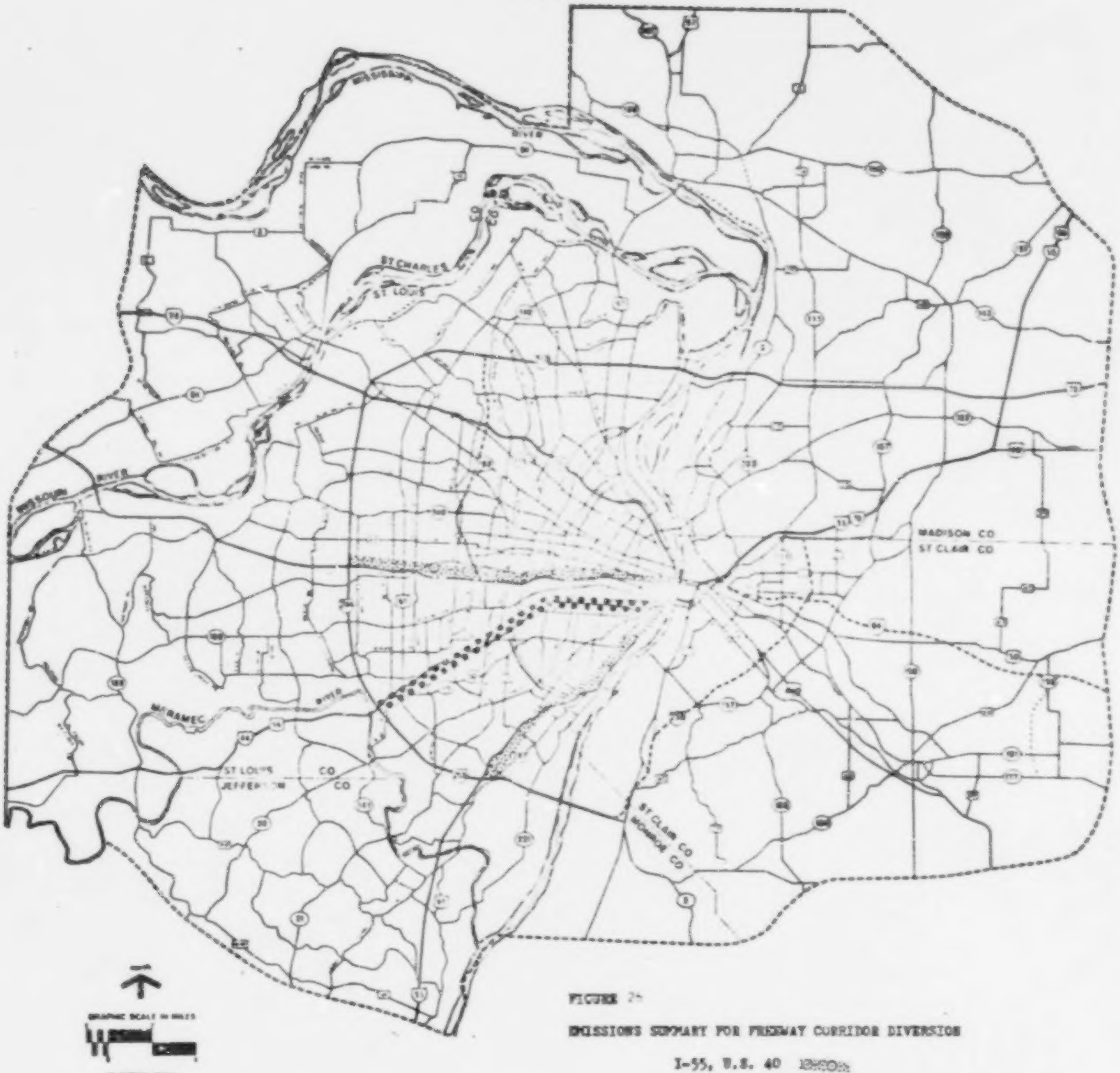

FIGURE 24

EMISSIONS SUMMARY FOR FREEWAY CORRIDOR DIVERSION

I-55, U.S. 40 ▨
I-44 ●

Freeway

	I-55 Original	I-44 Original	U.S. 40 Original	Total Original Facilities	I-55, U.S. 40 with Diversion
VMT (24 hours)	789,093	718,290	1,092,597	2,599,980	2,502,875
Emissions (kilograms/24-hour period)					
CO	17,763	15,131	24,473	57,367	59,534
NO_x	6,452	6,070	8,987	21,509	19,982
HC	3,220	2,834	4,446	10,500	10,513
Emissions Rates (g./veh.-mile)					
CO	23	21	22		24
NO_x	8	8	8		8
HC	4	4	4		4

TABLE 20

EMISSIONS SUMMARY FOR FREEWAY CORRIDOR DIVERSION

ADT with diversion, the VMT's for U.S. 40 are underestimates in this sensitivity analysis.

The results reflect the result of eliminating a corridor from use with current traffic loads, or the present impact if I-44 had not been completed. Again, the results are consistent with the literature with respect to impact of increased VMT and lowered average speed as saturation is approached on remaining I-55 and U.S. 40 after diversion. Total CO emissions are higher, total HC emissions are slightly higher, reflecting the above speed and VMT issues, and total NO_x is lower, reflecting impact of lowered operating speeds. Again, the total VMT's shown diverted, and resulting increase in emissions output is understated, due to the FHWA input limitations on ADT discussed above. The aggregate rates have raised slightly for CO, reflecting increased VMT loads on the remaining I-55 and U.S. 40 corridors, however, the lowered average speed component resulting from these flow increases on each corridor have yielded a stable aggregate NO_x rate. The aggregate combinations of altered speeds and changed VMT's over all links of both remaining corridors appeared to have a balancing effect on HC rates, with no apparent aggregate rate change.

The second sensitivity analysis examined the Innerbelt (Mo. 725) North-South corridor. One component section of this route is complete, and the analysis centered around hypothetically extending it North and South to become an effective North-South Freeway Corridor, and diverting traffic onto it from parallel high volume arterials. Figure 27 illustrates the hypothetical Innerbelt Freeway and the parallel arterials under study. The analysis consisted of diverting 50% of the traffic off each arterial and placing it on the Innerbelt. Baseline

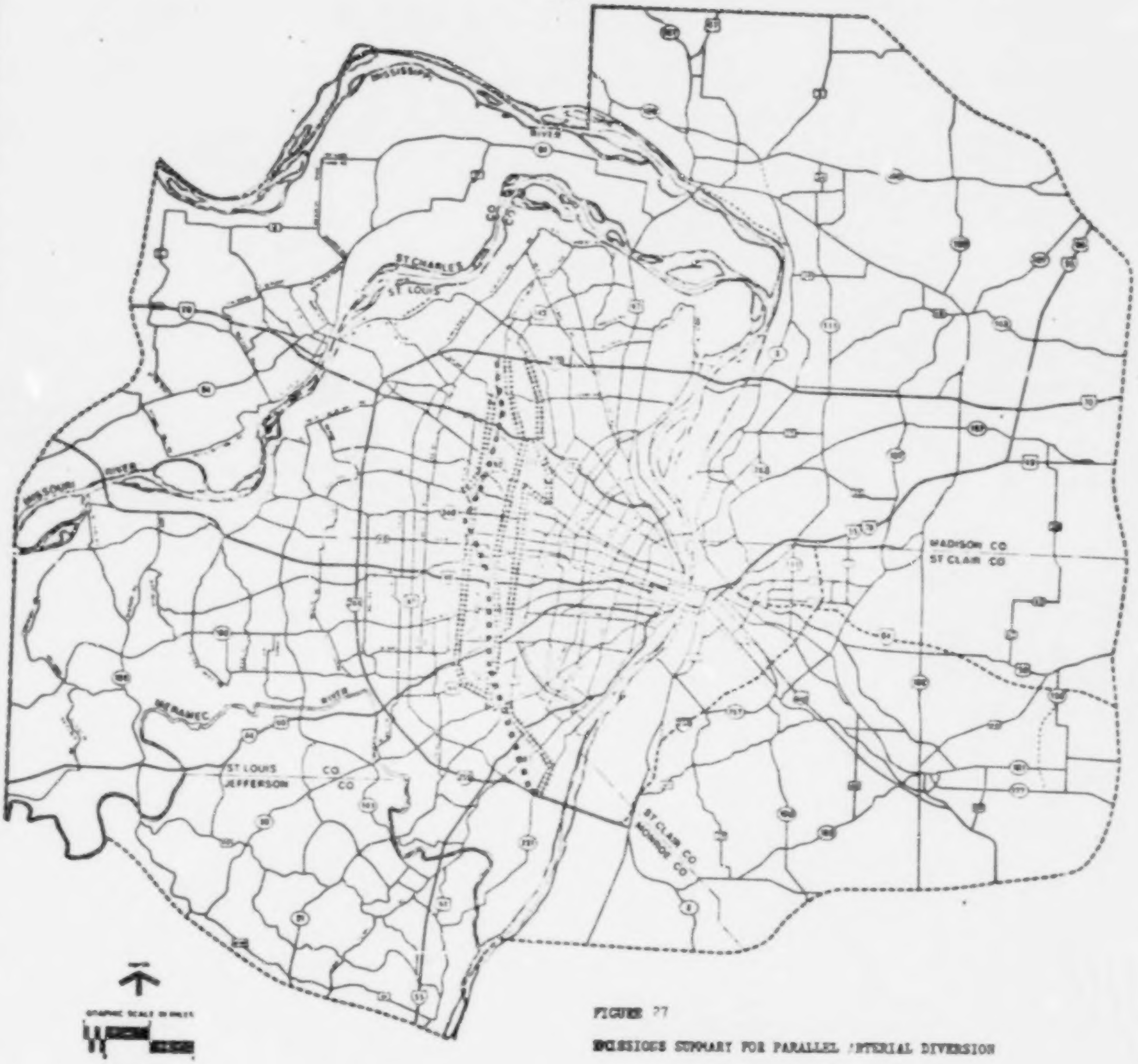

FIGURE 27

EMISSIONS SUMMARY FOR PARALLEL ARTERIAL DIVERSION

Parallel Arterials ▨▨▨
Hypothetical Innerbelt • • •

Routes

	(1) Parallel Arterials before Diversion	(2) Parallel Arterials after Diversion	(3) Hypothetical Innerbelt	(2) + (3)
VMT (24 hours)	451,042	220,896	261,992	482,888
Emissions (kilograms/24-hour period)				
CO	15,513	6,811	5,079	11,890
NO_x	2,565	1,279	2,312	3,591
HC	2,299	1,069	993	2,062
Emissions Rates (g./veh.-mile)				
CO	34	31	19	25
NO_x	6	6	9	7
HC	5	5	4	4

TABLE 21

EMISSIONS SUMMARY FOR PARALLEL ARTERIAL DIVERSION runs were made of arterial street emissions before and after diversion, and the hypothetical presently loaded Innerbelt. Table 21 summarizes the results of this sensitivity analysis. Present provision of the new freeway corridor facility, in light of current parallel arterial operations, yields a drop in total emissions of CO and HC, when compared to operation of arterials alone in column 1. Again, this is due to diversion of part of the aggregate traffic load to a facility with higher average speeds. Likewise, this increase in speed yields higher total NO_x emissions. The rates on the Innerbelt, given the constancy of total VMT and provision of higher operating speeds, have dropped as expected for CO and HC, and increased slightly for NO_x, when compared to arterial rates before diversion.

CHAPTER V

CONCLUSION

In concluding the reported research, it is relevant to point out the capabilities and information which have been provided, comment on further needed research to advance the state of the art, and discuss the general status of line source emissions modelling with respect to current knowledge about related traffic engineering phenomena.

A. Use and Applicability of Present Research and Modelling Results

The data analysis, model development, and integration with SAPOLLUT has yielded several tangible outputs. They are:

1.) A complete quantitative and relevant qualitative data base for freeways, principal arterials and minor arterials in the St. Louis Air Quality Control Region.

2.) A model format - NETSEN - which is capable of sorting and describing any subset of components of the above traffic network, at continually varying levels of detail, from gross geographic description of volumes only, to highly refined geographic locations possessing multiple attributes of traffic, geometric design, topographic, control and land use conditions which are significant in the link's operation and its relationship to emissions and/or air quality.

3.) The interface of the above format with the present operating rationale of SAPOLLUT, thus yielding the capability to model and describe the total emissions of CO, NO_x and HC emanating from a network described at a desired level of attributes, which have been used as input to NETSEN.

4.) Based on the most refined use of the above in the St. Louis Area, an extremely accurate statement of the line sources. This statement encompasses the sources, descriptions, attributes and total emissions resulting from 1,370 miles of roadway, composed of 195 miles of freeways, and 1,175 miles of principal and minor arterials. The complete description and discussion of these line sources is contained in Chapter IV.

5.) A capability to perform link by link sensitivity analysis on the types of attributes existing on one individual link, a corridor of several links, or an area of several individual street links. Thus, design characteristics and/or traffic loads may be altered or eliminated, for purposes of using SAPOLLUT to yield the resulting changes in aggregate emissions.

B. Recommendations for Further Research

As is expected from intensive research on any problem, the activities of data collection, logic development and model construction of NETSEN, and construction of its interface with SAPOLLUT, have yielded some insights into current gaps in the state of the art of merging information on the traffic and network phenomena with present emissions modelling. As such, several specific items represent areas of new or improved research focus which the research team feels should be pursued in future activity on this topic. They are:

1.) Future use of a model such as SAPOLLUT for basic research on current emissions behavior should be pursued in a highly different software format than SAPOLLUT currently employs. Specifically:

  a.) Use of any format requiring a loaded assignment network, including assignment on present networks should not be considered due to:

    1.) The complexities of intermediate software.

    2.) The theoretical issues surrounding the validity of assignment model forecast volumes, or assignment model loaded volumes on the present network vs. current ground count data. This is particularly relevant in the St. Louis Area at this time, due to vague relationships of assignment output vs. actual future foreseeable auto and transit networks in the region, as the comprehensive transportation planning begins a period of revision.

2.) The study team further encourages the development of a capability to use a highly detailed network descriptor model such as NETSEN, with an emissions model which can be interfaced directly with one of the output parameters from NETSEN without requiring an intermediate software battery to change input form. Preferably, the variable input from NETSEN to the emissions model would be a traffic flow theoretic variable having significance to both the tagged links in NETSEN and the emissions computation process.

3.) To this immediate end, it is recommended that NETSEN be run in conjunction with the Modal Emissions Model, which employs speed modes as input to emissions computations.[1] The speed mode concept, as part of the traffic flow theoretic envelope of speed and delay studies, and acceleration noise, it is a relevant and meaningful traffic flow parameter, and can be output as another link descriptor in NETSEN.

4.) Further, appropriate development, collection and use of speed mode or speed profile data should be undertaken by interested professional groups. Such activity is currently underway in the St. Louis Area, through contracts to East-West Gateway from the Federal Highway Administration and the Department of Transportation Systems Center. The activity focuses on driving patterns throughout the metropolitan area and the inherent speed profiles, volumes and spot speeds in such driving patterns. Effort should be directed to matching speed mode and profiles to links with specific groups of attributes, thus facilitating the capability of using speed mode as the critical transfer parameter from NETSEN through emission computations in a Modal Emissions Format. Comprehensive results relating research to speed modes should be possible through use of relevant field collection information to date, synthesized with appropriate use of the literature and flow-theoretic computations.

5.) Development and use of the capability to output emissions information on a link by link mapping is necessary. Current SAPOLLUT output is aggregate emissions by area type and functional class, rendering investigation of emissions intensity and sensitivity analysis somewhat cumbersome at the individual link and corridor level. It appears that employment of the Modal Emissions Model in a manner discussed in the previous paragraphs has the capability of allowing mapping of emissions output at an individual link level over the entire network entered for study.

C. Closing Comments on Status of Line Source-Traffic Attribute Modelling

In final conclusion, effort should be directed toward detailed filtering out of locations of attributes, and measurement of resultant emissions at these link locations, thus cataloging the simultaneous impact of these attributes on emissions. Further, the categorization of traffic operation on facilities should proceed by capturing theoretically sound aspects of flow activity categorized by situation type which are of relevance to emissions, such as queuing and delay descriptions at intersections, and shock wave phenomena on uninterrupted flow links and freeway bottlenecks. Thus, a mapping of network description, refined traffic flow parameters, and emissions will ultimately result, yielding a comprehensive format from which to investigate and calculate emissions.

Footnotes Chapter V

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[1] Automotive Exhaust Emissions Modal Analysis Model, EPA No. 460/3-74-005, United States Environmental Protection Agency, Office of Air and Water Control Program, Office of Mobile Source Air Pollution Control, Certification and Surveillance, Ann Arbor, Michigan, January, 1974.

BIBLIOGRAPHY

Selected Research Bibliography

A Study of Traffic Flow on a Restricted Facility, Interim Report Phase One, Department of Civil Engineering, University of Maryland, College Park, Maryland, June 1973.

"Air Pollution Controls for Urban Transportation," *Highway Research Record 465*, Highway Research Board, National Research Council, 1973.

"Air Quality and Environmental Factors," *Transportation Research Record 492*, Transportation Research Board, National Research Council, 1974.

"An Introduction to Traffic Flow Theory," *Highway Research Board Special Report 79*, Highway Research Board, National Research Council, 1964.

Automotive Exhaust Emission Modal Analysis Model, *EPA No. 460/3-74-005*, United States Environmental Protection Agency, Office of Air and Water Control Programs, Office of Mobile Source Air Pollution Control, Certification and Surveillance Division, Ann Arbor, Michigan, January, 1974.

Design of An Urban Speed Characteristics Study, Research Triangle Institute, Center for Development and Resource Planning, May 1974.

Drew, Donald R., *Traffic Flow Theory and Control*, McGraw-Hill, 1968.

"Highway Capacity Manual," *Highway Research Board Special Report 87*, National Research Council, 1965.

"Highways and Air Quality," *Highway Research Board Special Report 141*, Highway Research Board, National Research Council, 1973.

Hillier, Frederick S. and Liebermann, Gerald J., *Introduction to Operations Research*, Holden-Day, Inc., 1970.

Littman, Fred E., Semrau, Konrad T., Rubin, Sylvan, Dabberdt, Walter F., *A Regional Air Pollution Study (RAPS) Preliminary Emissions Inventory*, Stanford Research Institute, Menlo Park, California, January 1974.

Rossano, A. J. Jr., Ed., *Air Pollution Control Guidebook for Management*, Environmental Science Services Division, E.R.A. Inc., Stamford, Conn., 1969.

Scott Research Laboratories, Incorporated; Malcom Smith, *Development of Representative Driving Patterns at Various Average Route Speeds*; Prepared for the Environmental Protection Agency, Office of Administration, Research Triangle Park, North Carolina, EPA Contract Number 68-02-1301 (6-73), February 11, 1974, San Bernadino, California.

Selected Research Bibliography (Continued)

"Social, Economic, and Environmental Factors in Transportation," *Highway Research Record 356*, Highway Research Board, National Research Council, 1971.

Special Area Analysis Final Manual, Federal Highway Administration, Urban Mass Transit Association, Federal Aviation Administration, Office of the Assistant Secretary for Policy, Plans, and International Affairs, August 1973.

"Traffic Engineering..... A Tool to Reduce Air Pollution," *Traffic Engineering Magazine*, Vol. 44, No. 9, June 1974.

Venezia, Ronald A., "The Impact of Transportation Alternatives on Ambient Air Quality," Unpublished Ph.D. Dissertation, Washington University, January 1972.

St. Louis Area Traffic Data Sources

Peak Hour Travel Analysis, St. Louis Area, East-West Gateway Coordinating Council, February 1974.

Roadway Functional Classification Study for the Saint Louis Area, East-West Gateway Coordinating Council, July 1973.

Status of Missouri State Highways by Routes & Systems, Missouri State Highway Department, December 31, 1973.

St. Louis Area Transportation Study, Streets, Highways and Transit, East-West Gateway Coordinating Council.

St. Louis City Traffic Volume Studies, 1973, St. Louis City Department of Streets, Highway Division.

St. Louis County Traffic Volume Studies, 1973, St. Louis County Department of Highways and Traffic, April 1974.

St. Louis Metropolitan Area Traffic Volume Summary, March 1973-April 1974, Missouri State Highway Department, May 1974.

Traffic Characteristics on Illinois Highways, State of Illinois Department of Transportation, 1972.

Professional Interviews

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James F. Baumann	Deputy Traffic Commissioner, City of St. Louis
Frank Kriz Tom Dollous	Missouri State Highway Department, Division of Traffic, District VI Office, Kirkwood, Mo.
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PRELIMINARY

RAIL OPERATIONS AIR POLLUTION EMISSION STUDY PLAN FOR ST. LOUIS

D. A.Knapton
Raytheon Service Company

June 1973

Prepared for:
Department of Transportation
Transportation Systems Center
Kendall Square
Cambridge, Mass   02142

CONTENTS

Section Page

1.0 INTRODUCTION.................................. 1

2.0 EMISSION INVENTORY REQUIREMENTS............. 5

3.0 EMISSION INVENTORY METHODOLOGY.............. 8

3.1 INFORMATION SOURCES........................ 8

3.2 INVENTORY BASED ON PUBLISHED DATA...... 10

3.3 RAPID SURVEY INVENTORY.................. 12

3.4 COMPREHENSIVE SURVEY.................... 15

3.5 ENTENSIVE FIELD SURVEY.................. 18

LIST OF ILLUSTRATIONS

TABLE		Page
1	1967 EMISSIONS FROM RAIL OPERATIONS WITHIN 100 MILES OF ST. LOUIS (10^3 lb)	2
2	ST. LOUIS REGIONAL RAIL OPERATIONS AIR POLLUTION EMISSION SOURCE INVENTORY (Suggested Format)	4
3	SUMMARY OF RAIL EMISSION INVENTORIES	7
4	SUMMARY OF RAIL OPERATIONS EMISSION INVENTORY DATA SOURCES	9
5	TYPICAL RAIL LOCOMOTIVE DUTY CYCLE (1)	13
6	DIESEL LOCOMOTIVE EMISSION FACTORS lb/1000 gal. fuel	14
7	EMISSION INVENTORY OF ST. LOUIS RAIL OPERATIONS	17

RAIL OPERATIONS AIR POLLUTION EMISSION STUDY FOR ST. LOUIS

1.0 INTRODUCTION

This brief note summarizes procedures proposed by the Department of Transportation (DOT), Transportation Systems Center (TSC), for making an inventory of rail air pollution sources in the St. Louis air shed region. This activity will be part of the Technology for Environmental Analysis (TEA) program being conducted by TSC. The TEA program includes compiling inventories of selected transportation emission sources for the St. Louis Air Pollution Studies (SLAPS) project. The general background approach to making mobile source emission inventories for the SLAPS project was described earlier (1). This note concentrates on the rail emission source inventory methodology.

---

(1). "Waterborne Vessel Air Pollution Study Plan for St. Louis
Raytheon Service Company; June 1973.

Rail activity in the St. Louis region has been studied for many years. TSC recently estimated annual surface freight transportation exhaust emissions within 100 miles of St. Louis (1). These estimated rail exhaust emissions for 1967 were:

TABLE 1 1967 EMISSIONS FROM RAIL OPERATIONS WITHIN 100 MILES OF ST. LOUIS (10^3 lb)

EMISSION	
Particulates	97
SO_2	253
CO	273
HC	195
NO_x	292
Aldehydes	16
Organic Acids	27
TOTAL	1153

---

(1). Sturm, J.C., Railroads and Air Pollution: A Perspective U.S.D.O.T. Federal Railroad Administration, Report No. FRA-RT-73-33, Washington, D.C. (May 1973).

The rail inventory methodology for the SLAPS project will use existing source material when possible. Data previously used by TSC in their cursory St. Louis emission estimate and information being generated by the St. Louis Comprehensive Areawide Railroad Consolidation and Relocation study shoud be particluarly helpful.

The emission source inventory requirements and methodology described in this note is only a preliminary project plan. Changes will likely be made as inventory user needs become more definite.

TABLE 2 ST. LOUIS REGIONAL RAIL OPERATIONS AIR POLLUTION EMISSION SOURCE INVENTORY
(Suggested Format)

Activity	Number of Locomotives						Rolling Stock		Accid.	AUX. ENG.	Evap.
	Engine Horsepower						Refrig.	Tank	No. of Gal. and (type)	No.	No. of Gal. and (type)
	0-1000	1000 1999	2000 2999	3000 3999	4000 4999	5000					
Locomotives											
Main Line											
Local Freight											
Switching											
Rolling Stock											
Refrig.											
Tank											
Yard Operations											
Spillage											
Handling Losses											
Miscellaneous											
Burning											
Accidents											

2.0 EMISSION INVENTORY REQUIREMENTS

The rail emission source inventory will describe:

- the quantity of the sources by type and emission characteristics
- the location of sources
- their time occurrence

Position and time resolution will be developed during the program.

The comprehensive tabulation of emission sources by categories is shown in Table 2. The types and quantities of locomotives and fuel used will be examined early in the study. It is likely that diesel exhaust will be the most significant emission source and will be the major contributor of rail emissions. Other sources will be measured or estimated to determine if they should be included in the emission inventory. Decision to include or omit will be based on the degree of resolution of the atmospheric dispersion models and the emission rate and frequency of occurrence of the particular source.

The proposed TEA program to develop the rail emission inventory consists of a series of building blocks. The first of which will be an emission source inventory based on existing statistical data and by itself will provide a time average estimation of rail exhaust emissions. The inventory will also be the first step in building a data base for describing the location and time dependent characteristics of the rail emission sources. Several steps are planned in determining these spatial and temporal factors. However, each step will contribute to both further refinement of the emission inventory and greater detail of the information base for subsequent inventories of greater refinement.

The series of emission inventories with increasing accuracy of data follows the general classification of emission inventories outlined by the Committee on the Challenges of Modern Society in their report of air pollution in St. Louis and Ankara, Turkey.(1) A summary of the emission inventories characteristics is shown in Table 3.

---

(1) Anon. Air Pollution-Guidelines to Assessment of Air Quality, NATO Committee on the Challenges of Modern Society, (November 1971)

TABLE 3 SUMMARY OF RAIL EMISSION INVENTORIES

Type Inventory	Source Description	Position Resolution	Time Resolution
Based on Published Data	Exhaust Averages from literature	Region	Yearly Average
Rapid Survey	Exhaust Averages calculated from operators duty cycles	Terminals Mainlines	Weekly/Daily Average
Comprehensive	Exhaust and Evaporative Averages From Tests	Fine Grid	Weekly Average and Possible Daily Maximums
Extensive Field Survey	Individual Exhaust and Evaporative Tests	Fine Grid	Weekly Averages and Possible Hourly Maximums

3.0 EMISSION INVENTORY METHODOLOGY

3.1 INFORMATION SOURCES

The inventory methodology described here consists of several steps. Depending upon the specific needs of the inventory users, the methodology can produce a series of inventories of increasing refinements. The initial investigation is a simple average of rail operations exhaust emissions based on rail operating data and standard emission factors. This type of inventory for rail operations has already been estimated by TSC and needs only to be made current (Table 1). Subsequent mobile source inventories with increasing refonement of emission, location, and time factors will be generated as determined by user needs. Table 4 summarizes the data sources for different inventories.

The first step will be to contact the sources of information needed to compile the emission source inventory. It is expected initial contact will be made with:

1. EPA/NADB ?
2. St. Louis HUD Office
3. East-West Gateway Coordinating Council
4. Federal Railroad Administration
5. Local rail terminal and mainline operaters
6. City of St. Louis Air Pollution Control Division
7. Missouri Air Conservation Commission
8. Illinois Environmental Protection Agency

TABLE 4 SUMMARY OF RAIL OPERATIONS EMISSION INVENTORY DATA SOURCES

Type Inventory	Methods of Data Collection			
	Published	Field Visits	Source Tests	Area Tests
Based on Published Data	Yes	Some	No	No
Rapid Survey	Yes	Yes	No	No
Comprehensive Survey	Yes	Yes	Some	Some
Extensive Filed Survey	Yes	Yes	Yes	Yes

Early in the project, contact should be made with agencies having previously conducted rail traffic and emission surveys.

3.2 INVENTORY BASED ON PUBLISHED DATA

The emission inventory based on published data can be made using several methods, depending upon the availability of source data. If vehicle travel estimates are available, then emission rates can be estimated by using fuel consumption estimates and standard pollution emission factors.

If vehicle travel information is not available, then vehicle registration (vehicles in area of interest) can be used and average trips per unit time and trip characteristics (usually based on national averages) can be used to estimate travel demand. This will give an estimate of vehicle travel and an emission inventory can be estimated as before, based on fuel consumption and standard emission factors.

In some cases Census data can be used. If the freight ton-miles distribution of travel for the mode is known, and trips profiles can be estimated, it is possible to estimate fuel consumption, from which an emission inventory can be estimated. Other methods of applying aggregates vehicle operation characteristics can be used depending the availablity of information.

For the St. Louis Standard Metropolitan Statistical Area (SMSA), the annual ton-miles of freight shipments are available in the literature (1,2). In the past year, TSC made a cursory estimate of pollution emissions for the St. Louis region (Table 1). These figures are only an approximation and represent average yearly rail exhaust emissions for the 100 mile radius air shed of St. Louis.

---

1. 1967 Census of Trapsportation, Vol. III, Commodity Areas and Selected States, U.S. Dept. of Commerce, U.S.G.P.O., Washington, DC (1970)

2. Anon., Yearbook of Railroad Facts, Association of American Railroads, Washington, DC (1971)

3.3 RAPID SURVEY INVENTORY

A source inventory is compiled first for the rapid survey emission inventory. The sources are allocated by their performance classes and operational characteristics. The emissions are then calculated based on fuel consumption and emission factors. The following steps are required:

1. An inventory of rail locomotives used in the St. Louis region will be made. The inventory will be divided into the following operations:

   Main Line
   Local Freight
   Switching

   It will further be classified by engine characteristics:

   HP rating
   Type supercharging, if any
   2 or 4 stroke cycle

   Information sources for the locomotive inventory will be the rail operators.

2. An estimate of the daily operating characteristics or typical trip profile of the vehicles will be required. For rail operations, average duty cycles representing the time that the engine is used at the various power setting have been determined by several sources. One of these will be selected for use in the inventory.

Below is a typical duty cycle:

TABLE 5 TYPICAL RAIL LOCOMOTIVE DUTY CYCLE (1)

THROTTLE SETTING	TIME % BY TYPE		
	HEAVY	MEDIUM	YARD SWITCHER
8	24	20	Nil
7	2	1	Nil
6	3	2	1
5	2	2	1
4	3	2	2
3	3	3	4
2	3	4	5
1	5	5	10
Idle	46	59	77
Dynamic Brake	9	2	None
TOTAL	100	100	100

Throttle settings are related to percentages of maximum horsepower.

---

(1). Anon., Report on Exhaust Emissions of Selected Railroad Diesel Locomotives, Southern Pacific Transportattion, San Francisco, (March 1972).

3. The total horsepower hours can be calculated from the duty cycles of locomotives in the various classifications in the St. Louis inventory.
4. Total fuel consumed for the various classes of locomotives is calculated by a fuel conversion factor of 0.4 lb. fuel consumed /HP-hr.
5. The emission rates for the locomatives can be calculated using diesel locomotives emissions factors. Shown below are typical emission factors. New information on emission factors will be used as it becomes available.

TABLE 6 DIESEL LOCOMOTIVE EMISSION FACTORS
lb/1000 gal. fuel

SOURCE	CO	HC	NO_x	$HC+NO_x$	$SO_2{}^a$
1	124	-	-	623	-
2	133	94.2	374	-	-

---

(1). Anon., Report on Exhaust Emissions of Selected Railroad Diesel Locomotives, Southern Pacific Transportation, San Francisco, (March 1972).

(2). Hare, C.T., and K.J. Springer, Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines, Part 1, Locomotive Diesel Engined and Marine Counterparts, Southwest Research Institute, San Antonio, (October 1972).

3.4 COMPREHENSIVE SURVEY

The Comprehensive Survey is a refinement of the Rapid Survey. It would include building a basic data file for all categories of sources which are significant with the dispersion models. Location and time resolution degree will be determined by the dispersion model. This inventory model will include considerable amounts of file information and automatic data processing may be used. In addition, the basic source inventory and operating characteristics data may be compiled for future emission source and control models which can be programmed to reflect changes in rail activity and/or emission characteristics of the sources.

It is anticipated actual field testing will be needed for the Comprehensive Survey to obtain actual emission rates, particularly for the miscellaneous type emissions associated with rail activity. This includes such sources as evaporation from spillage and handling losses, exhaust emissions other than from locomotives, and various maintenance and operations sources assoicated with rail yard and main-line rail activity. In addition, duty-cycle surveys will likely be needed to specify more accurately the operational characteristics of the St. Louis railroads.

The general methodology is similar to that of the Rapid Survey described above, only that greater detail in all the significant emission sources are included for the location and time blocks.

The Comprehensive Survey technique will also show peak emission levels for the periods of high rail activity, instead of only average levels of the previous methods. The emission rates can be shown as in Table 7.

TABLE 7 EMISSION INVENTORY OF ST. LOUIS RAIL OPERATIONS

LOCOMOTIVE Engine HP	FUEL USAGE	FUEL USAGE,	FULE USAGE	EMISSIONS					
	YARDS AND TERMINALS	LOCAL FREIGHT	MAIN LINE	lbs/yr					
	gal/yr	gal/yr	lbs/yr	HC	NO_x	CO	SO_x	Other	Part.
0-1000									
1000-1999									
2000-2999									
3000-3999									
4000-4999									
5000- +									
Auxilary Engine									
Evaporation									
Spillage									
Misc.									
TOTAL									

3.5 EXTENSIVE FIELD SURVEY

This type of inventory includes considerable field testing and would likely be limited to support atmospheric dispersion model verification and control impact assessment, Only the development of montoring techniques, however, is being planned at this time.

Emission Models

This section of the handbook discusses the background information gathered on existing emission models at the start of the RAPS program (1). This information was given to the people who are developing the RAPS emission models as background information.

---

1. Regional Air Pollution Study (RAPS) Preliminary Emission Inventory, Standard Research Institute, PB 232-223/AS, January 1974

VII TASK E: EMISSIONS MODELING

A. Introduction

The specification of the rate and distribution of emissions is basic to any air quality simulation model. However, emissions per se have rarely been measured in modeling studies conducted prior to RAPS; usually, emissions are parameterized on the basis of available emissions-related data. The so-called emissions model is thus a methodology that relates available data to the required mass flux density of pollutant emissions.

Depending on the type of the emissions source and the requirements of the various air quality simulation models, emission models are conveniently classified according to the mobility and configuration and type of the source. Figure 14 is a three-dimensional matrix illustrating some 64 possible combinations of emission features that describe various emission model types. These are only broad classifications, and the number of real possibilities is considerably greater. Referring to the discussion of Task B, for example, we note that there are at least four major categories of gaseous pollutants to be considered: carbon monoxide (CO), oxides of nitrogen (NO_x), hydrocarbons (HC), and sulphur oxides (SO_x). Also, particulates may need to be classed as large ($> 2\mu m$) or small ($\leq 2\mu m$), while mobile surface emissions can be subdivided similarly as gasoline and diesel powered roadway vehicles, trains, on-ground aircraft, and so forth. The saving factors are that not all combinations exist in the real world, some are of no major concern, and others can be grouped and treated in a single approach.

Other constraints also limit the task of specifying the input requirements and the structure of emission models likely to be required in the RAPS. Many such constraining factors have already been discussed in other task reports. Emission model requirements are determined by the specific requirements of simulation models to be evaluated in RAPS. For example, the minimum emission-time resolution for most model applications is specified as one hour. (We do consider, later in this section, subhourly specifications for vehicular emissions.) Spatial resolution has also been addressed in Task B (Section IV), but an objective methodology for evaluating the required geographical resolution of major point sources is presented in this task report.

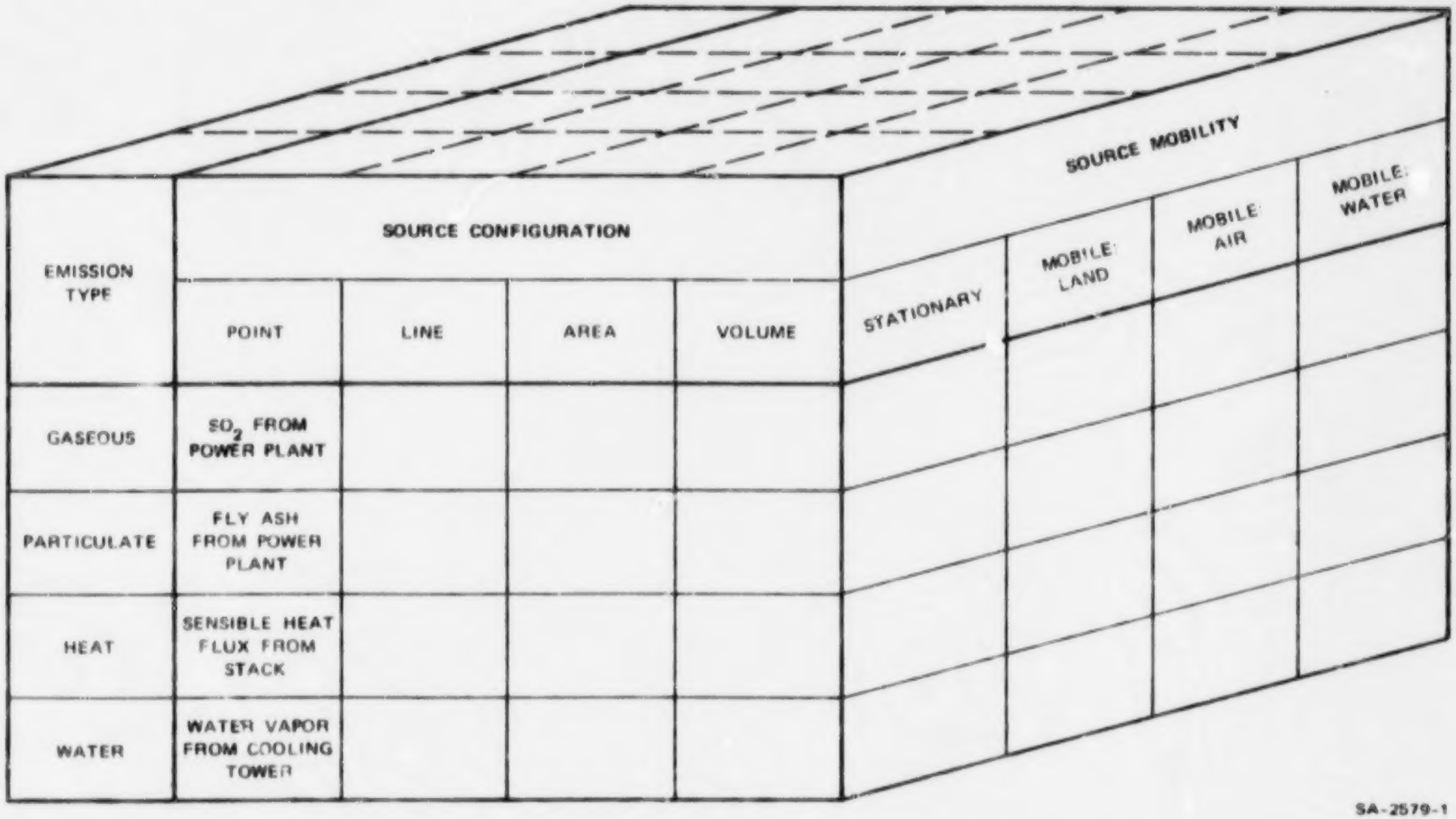

FIGURE 14 SCHEMATIC ILLUSTRATION OF CLASSIFICATION MATRIX FOR EMISSION MODELS

B. Modeling

1. Review of Existing Models

An extensive and in-depth review of the available literature on emissions modeling resulted in the identification of 28 papers and reports deemed significant in the context of this RAPS study. Appendix B summarizes these models by listing (1) the author's abstract, (2) our summary of the significant features of the models, and (3) the form and availability of documentation. Table 23 lists the models reviewed and summarizes the models according to emissions type, source mobility and configuration, and the degree of experimental verification. The last aspect is particularly important to RAPS where appropriate short-term specification of emissions is essential to the overall evaluation of air quality simulation model performance. In this regard, it is significant that only three of the 28 models reviewed have undergone independent experimental evaluation of the emission estimates.

While Table 23 provides an overview of the emission models, Table 24 lists details of the input requirements and outputs of selected emission models. Generally, these models are the more comprehensive ones reviewed; as such, they reflect the state of the art and outline the facility and process parameters needed to simulate emissions from the smaller sources (discussed under Task B). In Table 24, the input requirements of the various models surveyed are subdivided into model inputs and model parameters, two categories with subtle distinctions. The attempt was to list as model parameters those data that are essentially internal to the emission model in that they are usually specified only initially. Of course, they may need to be revised periodically as updated or more representative values become available. Model inputs on the other hand encompass operational inputs required to actually run the model and generate emission rates. The classification system should not be viewed as rigid or formal, but rather as a convenience.

The discussion in Section IV points out many of the inadequacies of emission modeling techniques for use in a research program focused on the development and evaluation of air quality simulation models. In the past, emission data have been derived primarily from long-term average emission estimates--especially for the stationary sources. In turn, most of the long-term data have been derived not from direct measurement, but, by applying emission factors to survey information (e.g., fuel consumption). Hourly emission estimates (and finer spatial resolution) have then usually been derived from simulation techniques surveyed in this review. The resulting aggregation of emission factors and correlation and algorithms

Table 23

SUMMARY OF CONTENT OF EMISSIONS MODELS REVIEWED

Section Number in Appendix B	Emissions Model	Emissions Type				Source							Field Evaluation			
						Stationary			Mobile							
									Surface		Aerial					
		Gaseous	Particulate	Heat	Water	Point	Area	Volume	Line	Area	Line	Area	None	Minimal	Moderate	Extensive
I	Argonne National Laboratory	X		X		X	X						X			
II	Argonne National Laboratory	X								X			X			
III	ESSA	X					X								X	
IV	Federal Highway Administration	X							X					X		
V	Free University of Berlin	X				X	X						X			
VI	General Electric	X							X					X		
VII	General Research Corporation	X				X	X			X		X	X			
VIII	Geomet	X		X		X	X						X			
IX	IBM	X				X	X						X			
X	IBM	X				X	X								X	
XI	Metropolitan Washington Council of Governments	X								X			X			
XII	NAPCA						X									
XIII	NAPCA	X								X			X			
XIV	Northern Research and Engineering	X	X							X		X		X		
XV	Ontario Department of Environment	X	X			X	X		X	X			X			
XVI	Pacific Environmental Services	X				X	X			X			X			
XVII	Rutgers University	X	X							X		X	X			
XVIII	Sacramento Regional Area Planning Commission	X	X				X			X		X	X			
XIX	Stanford Research Institute	X							X	X					X	
XX	Stanford Research Institute	X							X				X			
XXI	Stanford Research Institute	X							X					X		
XXII	Systems Applications, Inc.	X					X	X		X		X	X			
XXIII	Systems Development Corporation	X				X	X			X		X	X			
XXIV	Travelers Research Corporation	X				X	X						X			
XXV	TRW	X								X				X		
XXVI	University of Alaska				X	X	X		X				X			
XXVII	University of California, Davis	X								X			X			
XXVIII	U.S. Weather Bureau	X				X	X						X			

Table 24

EMISSIONS MODELS INPUT-OUTPUT SPECIFICATIONS

Model	Model Output	Source	Model Input	Model Parameters
Argonne (See Reference 2)	Hourly SO_2	One square mile area (residential/commercial/institutional)	Hourly average temperature Hour of day	Annual SO_2 emissions Fraction of annual fuel used for hot water Hours that heating cycle begins and ends Average number of degree days per year
	Hourly SO_2 and thermal emission rate	Power plants	Average daily temperature Hour of day Day of Week Month of year	Average annual percent coal used Average annual percent oil used Percent sulfur of coal Percent sulfur of oil Graph of peak load versus temperature by season Weekday and weekend seasonal graphs of system load versus hour of day Individual unit loads versus system load for each unit Thermal input versus unit load
	Hourly SO_2 and thermal emission rate	Industrial point sources	Average daily temperature Shift Day of week Month of year	Maximum space-heating thermal load Maximum process load Average annual percent coal used Average annual percent oil used Percent sulfur of coal Percent sulfur of oil Shift weighting factors Monthly fuel use weighting factors
Geomet (See Reference 3)	2-hourly SO_2 (See Reference 17 for description of this method.)	Industrial point sources	Hour of day Day of week Hourly temperature	Peak process SO_2 emission rate Annual number of degree days Annual fuel usage by type SO_2 emitted per unit fuel consumption (by type) Daily average fraction of peak process emission rate Winter season degree days Fraction of annual fuel usage in winter Commercial fuel usage correction factor
	2-hourly SO_2 and stack volume flow rate	Power plants	Hour of day Power output for the hour	Peak power output SO_2 emission factor Percent sulfur of fuel Fuel flow rate versus power output Stack volume flow rate versus power output

Table 24 (Continued)

Model	Model Output	Source	Model Input	Model Parameters
Gecmet (continued)	2-hourly SO_2	Area sources (5,000 square feet) (residential/commercial/institutional)	Hour of day Hourly temperature Number of fuels used	Summer day fuel consumption as a fraction of average winter day Average winter degree day Duration of season SO_2 emission per unit fuel (by type) Number of commercial sources Fraction of annual quantity of fuel (by type) used in summer season Annual quantity of fuel used (by type) Average number of rooms per dwelling unit Number of residential dwelling units using various fuel types Average annual U.S. household space Heating energy requirement - units Average number of rooms per U.S. household Average annual U.S. degree days Heating efficiency of fuel (by type) Commercial diurnal variation factor Winter season degree days Fraction of annual quantity of fuel (by type) used in winter season River vessel SO_2 emission rate Base automotive SO_2 emission rate Diurnal automotive variation factor Railroad SO_2 emission rate Backyard burning SO_2 emission rate Number of industrial sources Base industrial process emission rate Industrial day-of-week variation factor Industrial diurnal variation factor Residential fuel usage correction factor Commercial fuel usage correction factor
	Hourly SO_2 (See Reference 2 for description of method)	Area sources (one square mile) (commercial and residential)	Hourly average temperature Hour of day	Annual SO_2 emission Fraction of fuel used for hot water heating Annual number of degree days Diurnal fuel usage factor Hours fuel usage per day Commercial temperature correction factor Residential temperature correction factor

Table 24 (Continued)

Model	Model Output	Source	Model Input	Model Parameters
Gaumet (continued)		Power plants Same input and output as in Reference 1 except algorithm directly apportions emissions to individual stacks and thus requires fraction of emissions from ith unit going to jth stack Industrial point sources As above, except require additionally fraction of emissions going to jth stack		
IBM (See Reference 18)	2-hourly SO_2	Area sources (space and hot water heating)	Daily mean temperature Hour of day	Annual SO_2 output Average annual degree days Fraction of sources due to hot water heating Fraction of sources due to space heating Diurnal emission variations Total number of area sources Number of different area source sizes used Number of area source grids in each area source size Number of rectangular regions for entire source grid x, y coordinates denoting limits of regions and size of source grid for that region
NAPCA (See Reference 17)	2-hourly gas and steam send-out	Space heating sources	Hour of day Day of week Hourly temperature (ambient)	Usage factors for gas and steam by hour of day and day of week (generated by model) Regression constants from daily steam (or gas) output rate by daily temperature
Ontario Department of the Environment (1971)	Hourly CO, NO_x, and HC from automotive by one square kilometer areas	Area sources for one square kilometer Automotive emissions	Roadway class Hour of day Day of week Season of year	Vehicle count per day per grid square Road length in each grid square Emission factors Diurnal factors (speed and volume) Daily factors (volume) Seasonal factors (volume)
	Hourly SO_2, NO_x, CO, HC, and particulates by one square kilometer areas	Shipping, railroads, aircraft, gasoline storage, apartments, schools and universities, industrial, commercial, public buildings, and residential emissions	Average daily temperature Hour of day Day of week Season of year	Annual emissions Diurnal emission factors Daily emission factors Seasonal emission factors Annual number of degree days Dwelling type Fuel type

Table 24 (Continued)

Model	Model Output	Source	Model Input	Model Parameters
Ontario Department of the Environment (continued)	Hourly SO_2, NO_x, HC, and particulates for point sources greater than 100 pounds per day	Point sources - emissions greater than 100 pounds per day	Average daily temperature Hour of day Day of week Season of year Shift	Annual emissions Diurnal factors Daily factors Seasonal factors Annual number of degree days Space heating correction factor Fuel type
SAI (See References 1 and 3)	Hourly NO_x, CO, and hydrocarbons	Area sources for two square miles Automotive emissions - exhaust	Day of week Minute of day	Fraction of vehicle registration that are autos Emission rates from trucks and buses Distribution of vehicle trip-start times Ratio of cold-start to total starts during time intervals Emissions from a vehicle during a time interval after a cold-start Emissions from a vehicle during a time interval after a hot-start Average emission rate by pollutant from an auto over period between 7-1/2 and 22-1/2 minutes after a cold-start Average emission rate by pollutant from an auto over period between zero and 7-1/2 minutes after a cold-start Fraction of daily nonfreeway traffic count assignable to hourly period Nonfreeway vehicle mileage per day Average speed in fast and slow directions Coefficients from average speed and hot running emissions rate, by pollutant Diurnal factors for freeway traffic counts Freeway vehicle mileage per day Traffic counts as a function of time for selected streets to give ratio of vehicle miles driven in fast and slow directions Federal driving cycle (FDC) hot-start emission factors FDC cold-start emission factors
	Hydrocarbons (g/mi)	Automotive emissions, blow-by		Blow-by emission rates, by auto year and type (controlled or uncontrolled) Registration figures by auto year and type
	Hourly hydrocarbons	Automotive emissions, evaporative	Hour of day	Average daily tank and carburetor evaporation losses Number of automobiles in area Total nonfreeway vehicle mileage Distribution of nonfreeway vehicle miles per day

Table 24 (Continued)

Model	Model Output	Source	Model Input	Model Parameters
SAI (continued)	Hourly CO, NO, NO_2, and hydrocarbons	Aircraft emissions, ground operations	Hour of day	Diurnal distribution of total daily flights Fraction of airport area belonging to a particular grid square Number of flights per day for each aircraft class Average number of engines for each aircraft class Pounds of each pollutant per 100 pounds fuel for each class operating in each mode Pounds of fuel consumed per engine of each class operating in each mode
	Hourly CO, NO, NO_2, and hydrocarbons	Aircraft emissions, flight operations	Hour of day	Diurnal distribution of total daily flights Number of flights per day for each aircraft class Average number of engines for each aircraft class Time spent in descent from inversion height to touchdown, by aircraft class Time spent in descent from 3000 feet above ground to touchdown, by aircraft class Pounds of fuel consumed per engine during descent from 3000 feet, by aircraft class Fraction of length of flight path assignable to each cell Molecular weight of pollutant Volume of cell Molal volume of an ideal gas at one atmosphere and 60°F
	Hourly NO_x and low and high reactivity organic gases	Oil refineries	Crude capacity of refinery	Total daily refinery emissions for each pollutant Proportionality factors for crude refinery capacity
	Hourly NO_x	Petroleum marketing, domestic, ship and railroad emissions	Hour of day	Daily emissions from each source Population density distribution
	Hourly NO_x	Incineration, mineral processing, metallurgical plants, petroleum production (five square miles)	Hour of day	Total daily emissions Spatial distribution of ratios of permits issued in an area to total permits issued
	Hourly NO_x	Other industries	Hour of day	Total daily emissions Population density distribution
	Hourly organic gases	Petroleum marketing, dry cleaning, degreasing and other uses of organic solvent	Hour of day	Total daily emissions Population density distribution
	Hourly organic gases	Surface painting and coating operations	Hour of day	Total daily emissions Spatial distribution of ratios of permits issued in an area to total permits issued
	Hourly organic gases	Petroleum production		Total daily emissions Spatial distribution of ratios of permits issued in an area to total permits issued

Table 24 (Concluded)

Model	Model Output	Source	Model Input	Model Parameters
SAI (continued)	Plume rise	Volume sources Power plants	Season of year Hourly emissions	Wind speed Heat emissions from stack Average wind speed at stack height Average density of ambient air Specific heat of air at constant pressure Temperature differences between top and bottom of inversion Temperature of ambient air
SRI (See Reference 4)	Hourly CO	By link vehicular emissions	Link volume Facility type or average speed on link Time of day	Emission factors Diurnal factors Link distance End of link (node) coordinates
SRI (See Reference 19)	CO, HC	By link vehicular emissions	Link volume Operation mode Time resolution	Emission factors Calendar year Link distance Link capacity
TRW	Hourly CO, HC, NO_x	Vehicular emissions per one mile grid	Time of day	Emission factors Vehicle miles traveled, by grid Average speed for links in grid
University of Alaska (See Reference 20)	Gross aqueous emissions	Gasoline, coal and fuel oil combustion sources	Consumption	Fuel type Water content
		Cooling ponds		Temperature gradient (pond) Pond open area Conductivity Surface water temperature Air temperature regime Cloud cover
		Sewage treatment, open mines, people and animals breathing		
Northern Research and Engineering (1971)	Hourly SO_2, NO_x, CO, HC, and particulates	Aircraft	Type of aircraft Frequency of aircraft operations (landing and takeoff) Operating mode (idle, taxi, takeoff, landing)	Aircraft emission rate by operating mode and by aircraft type
		Aircraft ground support equipment	Type of equipment Operating time per hour	Emission rate by equipment type
		Space heating of terminal	Btu required or fuel consumed per hour	Emission rate per Btu generated or fuel consumed
		Vehicles within airport boundary	Types of vehicles Number of passengers Passenger load factors Operating time per hour	Emission rate by vehicle type

for the simulation of high resolution spatial and temporal emissions is, thus, defined as the emission model. Because of the uncertainties and potential for error in these methods, an emission inventory system for RAPS that relies heavily on measurement techniques has been proposed. However, two areas have been identified where the measurement approach is not feasible and where the use of simulation techniques is recommended. As discussed in Section IV, small stationary sources fall into this category. And it will be shown here that the magnitude of the mobile emission (i.e., roadway emission) network requires the use of emission simulation techniques together with some special measurements.

In spite of the limitations of many of the emission models, we have sought to identify those models that are appropriate to the treatment of small stationary sources and mobile sources. We have also included models that have heretofore been used to simulate emissions from the larger point sources; without the special, direct measurements recommended in Section IV, these models would provide the best (though admittedly coarse) emission estimates for these sources. Having thus placed in perspective the role of emission models in RAPS, we discuss below a cross section of models and the needs they appear to serve.

- The Argonne Model of Roberts[2]* for the simulation of hourly SO_2 emissions from distributed residential, commercial, and institutional sources, and for hourly SO_2 and thermal emissions from major point sources.
- The emissions model developed at Systems Applications, Inc. (SAI), by Roberts[1,3] for hourly stationary point and area source emissions of NO_x and hydrocarbons. This model is also recommended for the simulation of vehicular NO_x, CO, and hydrocarbon emissions subject to one reservation. The SAI aggregates vehicular emissions into two square mile area sources--a feature that may be too gross for direct application to RAPS. Therefore, we suggest that the SAI model be modified to provide link-by-link emissions for the major links in the manner of the Stanford Research Institute (SRI) model of Ludwig[4] while retaining the spatial averaging (on the smaller scale of one square kilometer) method for the secondary links.

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*Model reports are reviewed in Appendix B.

- The Geomet model[8] for diurnal emissions from river vessels and railroads.
- The Platt's model for Northern Research and Engineering,[8]* for aircraft emissions.

Several categories of emissions are notable by their absence from the above listing. To the best of our knowledge, there are no models available that treat heat emissions from vehicular or distributed area sources although the inputs to such models already seem to be required in the SAI, SRI, Geomet, and Argonne models. However, appropriate thermal emission factors are required. Another shortcoming of the available models is the treatment of particulate emissions. While four of the 28 models reviewed treat particulates, none provides output on size distribution.

Furthermore, very little has been done to develop a regionally applicable model of man-induced water vapor emissions. To be sure, the knowledge and expertise are available to develop such a model, but a rigorous and comprehensive methodology has not been compiled. Perhaps the closest facsimile to what is required is the work at the University of Alaska by Benson[20] for Fairbanks, Alaska, where water is considered a primary atmospheric pollutant in winter. Thus, we recommend the use of an aqueous emissions model, similar to Benson's, but expanded as discussed later.

Lastly, the emissions modeling work of the Ontario Department of the Environment for Toronto is perhaps the singularly most comprehensive, available methodology; it is not, however, generally available. We suggest that official requests be submitted to the Ontario Department of the Environment since many of their methods and experiences might be of benefit in the development of the RAPS emissions inventory.

2. Specification of Emissions

The basic requirement of the RAPS emissions inventory program is to provide hour-by-hour emission rates for the various pollutants and heat and water vapor. The pollutant emissions are of primary importance

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*This model is currently being modified by Geomet under Contract 68-02-0665 with the Meteorology Laboratory, Environmental Protection Agency, Research Triangle Park, North Carolina.

(they specify the basic emission inventory requirements), while heat and water vapor can be determined from data acquired in the course of listing the pollutants (see Task B).

For stationary sources, there is a three-stage sequence in which emissions should be specified in RAPS.

(1) Direct measurement of emissions.

(2) Measurement of inputs to the pollutant-generating process with subsequent parameterization of the input-output (i.e., emissions) relationship.

(3) Parameterization of both the inputs and input-output relationship.

An example of the first would be the use of in-stack monitors at major power-generating facilities. The second method would employ measurement of process parameters directly related to emissions (e.g. fuel consumption rate), while in the third case these parameters might be determined from a statistical base or as a function of a known indirect indicator (e.g., degree-hours). Prior to RAPS, regional studies employed the third method almost exclusively. In RAPS, however, greater emphasis must be placed on the first and second methods.

a. Stationary Sources

Direct monitoring (input or output) of all stationary sources is not practicable in view of financial constraints, nor is it required; hence, there is a need for emission models. The available inventories for Saint Louis have been reviewed in discussions of Tasks B and D to identify the number and size of the major point sources of SO_x and NO_x (CO and HC are emitted primarily by distributed sources). A major point source may be considered as one that receives individual treatment in an air quality dispersion model, not one that is aggregated into an area source. About 13 point sources (e.g., power-generating plants) have been identified as "principal" major emitters with emission rates far in excess of "secondary" major point sources. As a first step, we have proposed (Task B) routine emissions monitoring for all principal sources and routine input monitoring for secondary point sources. Routine input or emissions monitoring is not required for the remaining individual stationary point and area sources. The best available emissions models will serve adequately.

The types of input or emissions measurements recommended above for various stationary sources are those necessary to provide the accurate and current emissions inventory required as input to the operation or evaluation of mesoscale air quality simulation models. Where the intent is to investigate microscale phenomena, the basic or routine inventory will need to be supplemented with special emission inputs. Depending on model receptor locations (or the location of air quality monitoring stations), it may be necessary to provide higher resolution emissions data for some of the lesser sources. Thus, for example, minor point sources near a particular receptor may either need to be monitored continuously or, at least extensively, during selected periods. More specific requirements cannot be set until actual monitoring sites are determined or specific research studies defined. This is especially true for emissions from mobile sources; further considerations along these lines are presented later in this section.

b. Mobile Sources

For routine use, the mobile emission inventory should be estimated for link or line source geometry using an average route speed model formulation such as that used in APRAC-1.[21] Links are straight segments of major arterial streets and freeways that serve as the transportation network for the area. In most urban complexes, this kind of network has about a one-half to one-mile span in suburban areas and a one-block span in downtown areas. The link geometry is recommended because it is conveniently related to the parameters needed to estimate emission, links can conveniently be aggregated into area sources (but not the reverse), and control strategies to be investigated later will deal with modifications of the locations or conditions on the links (not the areas).

The mobile emission inventory is thus envisaged to comprise three distinct elements: (1) the basic roadway network, (2) traffic characteristics, and (3) an emissions model. The first element is a listing of the characteristic features of each link in the roadway network, such as

- Link location (geographical location of the endpoints).
- Facility type (e.g., suburban freeway, downtown arterial).
- Roadway characteristics (e.g., number of lanes, grade, elevation, foundation).

Traffic characteristics are those parameters that describe the vehicle population and traffic flow. In this category, the inventory must contain data on

- Vehicle mix by age and type (e.g., numbers and ages of light duty vehicles and heavy duty diesel and gasoline-powered vehicles).
- Vehicle speed (by facility type and location).
- Distribution of origin-destination (O-D) locations.

Because vehicle emissions cannot be measured directly in situ, they need to be determined with the aid of an emissions model using traffic and roadway data in the manner of Roberts' model[2] or Ludwig's model.[4] (A number of other sources discuss the requirements and availability of roadway and traffic data.)[22,23,24,25,26] As indicated above, we recommend the use of the average-speed emissions model on a link-by-link basis as the primary mobile emissions format; in this manner, area-averaged emissions can be obtained appropriate to the dispersion model structure or individual-link data could be retained for the larger roadways for line-source models. We further suggest that O-D data be used to identify cold-start emission contributions. Lastly, a multimodal emission model should be used for individual microscale studies. But the collection of the appropriate data and the operation of the model to generate emissions data should not be a part of the basic inventory; rather it may be considered as a separate task of the individual miscroscale study. Lastly, we note that the use of multimodal models[19] is still in a preliminary stage pending the availability of emissions test data.

The average route speed model requires inputs of traffic volume on the links and link speed. Diurnal traffic factors and emission factors for the vehicle mix on the link are also parameters of the model.

There is enough similarity of utilization (volume) on most urban streets that estimates based on periodic samples, supplemented by data from fixed sensors on high-volume freeways and on selected arterial streets will serve the purpose. These periodic samples are routinely taken by the traffic department as part of monitoring the adequacy of the street system. The volume data from these surveys are expressed in average daily traffic and require a diurnal pattern to convert the daily into hourly traffic. For this reason, monitors capable of hourly or finer resolution should be installed on typical streets representative of different usages: arterials at various distances from the center of town, arterials with various functions (downtown distributor; suburban collector; shopping center, university, or airport service). These different functions may imply different diurnal variation patterns and, hence, should be monitored. In addition, fixed monitors in such places will help to determine the variation by day, week, or season; from these data, factors for similar facilities may be developed and used for the emission models.

As in the hourly variation patterns, speed (and hence emissions) vary with volume of traffic, but speed distribution will be similar from day to day. Speed data are needed for the same kinds of facilities as those described above, and both fixed and portable monitors capable of providing speed information should be used.

Special consideration should be given to the inclusion of cold-start emission effects. Martinez, Nordsieck and Eschenroeder[27] have evaluated the comparative impacts of cold- and hot-start emissions (vehicular HC, NO, and CO) for Los Angeles in the time period from 0600 to 0900. Their findings are shown in Table 25 expressed as the ratio of emissions with cold start to emissions without cold start.

Table 25

RATIO OF COLD-START EMISSIONS TO
HOT-START EMISSIONS

Species	Year			
	1968	1971	1974	1980
NO	1.15	1.16	1.16	1.01
CO	1.48	1.57	1.53	2.30
Reactive hydrocarbons	1.08	1.10	1.11	1.11

We see that the neglect of the cold-start emissions contribution would have a moderate impact on the estimation of reactive hydrocarbons and a severe impact on CO by 1980. The emission inventory must therefore provide cold-start emission factors. Martinez[27] provides values that may be used for light-duty vehicles through 1976; these are summarized in Table 26.

Table 26

COLD-START EMISSIONS FROM LIGHT-DUTY VEHICLES

Model Year	Cold-Start Emissions (gm/start)		
	NO_x (as NO_2)	HC	CO
≤ 1968	5.66	10.73	254.1
1969	6.56	9.54	143.6
1970	5.39	10.88	143.3
1971	5.36	6.18	92.53
1972	4.02	4.25	76.74
1973-74	3.78	4.25	76.74
≥ 1975	-1.04*	2.68	43.06

*The negative factor is, of course, used in conjunction with the running emission factor, thereby effectively reducing net NO_x emission.

Under special conditions, as when forecast values of air quality are compared with measured values, continuous and detailed monitoring of vehicle behavior in the immediate environment of the measurements may be required with emissions being forecast with a multimodal emission model such as Ludwig's (reviewed in Appendix B). Such monitoring would not be done area-wide or continuously, because it is not appropriate to mesoscale studies. The multimodal model contains emission factors for the standard vehicle maneuvers: steady driving, slowing and speeding, stopping, and accelerating from a stop. Hence, the resolution of the model in space can be adjusted to the location and needs of the experiment. That is, a downtown block might be divided into several links, each a few tens of meters long. Vehicle modes such as acceleration, steady driving, congested driving, or stopping, would be assigned to each link. Volume in each link would be measured on a time scale comparable with the needs of the experiment.

Special microscale studies of vehicle-generated emissions may require subhourly inputs of vehicle parameters. This is especially important when the distribution of inert pollutants in heavily traveled areas is evaluated (e.g., CO in the central business district or in the corridor of major freeways). For such situations, 15-minute resolution may be necessary. In the earlier discussion on special measurements of stationary emissions, specific details of special mobile emissions requirements must await formalization of the plans for individual research studies.

c. Water Vapor Emissions

A special aspect of the overall emissions modeling program (both for stationary and mobile sources) is the treatment of aqueous emissions. As noted earlier, a comprehensive regional model for water has not been developed although emission factors are available at various levels of refinement. For example, Benson[20] presents emission factors for water (and carbon dioxide) emissions from the combustion of gasoline, fuel oil, and coal. For gasoline and fuel oil, emissions of water are readily specified on the basis of spatial and temporal distributions of fuel consumption. These will generally be available directly from the basic inventory of the other pollutants (e.g., SO_2, CO). Two exceptions may be surface vehicles and major point sources. For the former, the link inventory will provide facility type and vehicle volume, mix, and speed information; additional factors (or submodels) will therefore be required to obtain gasoline consumption. Direct monitoring of water emissions from large point sources may not be the optimum method. Rather, grab samples as discussed in Section IV may be more appropriate both because of economies of the method and because of relative invariability of the exhaust water content. These would then be related to the more available information on fuel and process features.

The man-induced emissions of water from air conditioning (ac) units, small cooling ponds, sewage treatment plants, and so forth should be aggregated into gross composite emissions for specified areas of the order of one to two kilometers on a side. For ac units, statistical relationships based on an inventory of ac capacity and type and the ambient conditions of wind, humidity, and temperature would be adequate to estimate the corresponding emission rates. Similar procedures could be used for cooling ponds and the like; for sources of this type, the inventory should contain information on the area and volume of the ponds, input water temperature, and degree of mechanical mixing. The emission rate is then determined for the appropriate time and location using an analytical or statistical model of potential evapotranspiration.

However, rather than calculate the emissions of water from the measured or prescribed inputs, we recommend that such "meteorologically-controlled" aqueous emissions from man-induced sources be determined outside the RAPS emissions inventory. We view these sources as those in which man's activities provide the potential (i.e., a water supply) for aqueous emissions to the atmosphere but in which meteorological processes regulate the magnitude of the vapor flux. In summary, aqueous sources in this category include the following:

- Cooling ponds
- Sewage treatment ponds
- Irrigation
- Space cooling units.

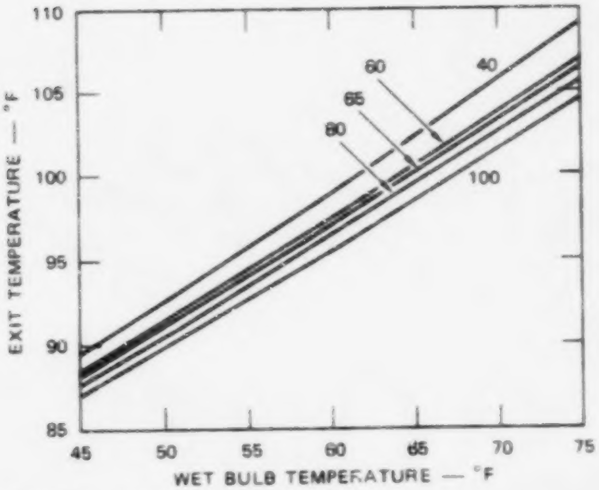
Lastly, anomalous sources of aqueous emissions, in particular, wet cooling towers with their enormous outputs of water vapor and their significant impact on visibility, gaseous reactions, and such, must be considered. For example, moisture discharge rates for very large power plants (e.g., 2,000-MW fossil steam plants) are of the order of 1.5×10^5 lb/min--a rate equivalent to the daily deposition of a 1-cm column of water on a 10-km^2 area.

To simulate these emissions accurately, the inventory should contain the design performance standards and power generation rates for each source. The environmental parameters required in the inventory are the ambient wet bulb temperature and relative humidity. Figures 15 and 16 illustrate performance curves for a natural-draft cooling tower that dissipates 8×10^9 Btu/h; note that the performance curves are also used to estimate the sensible heat output of the tower as required for the thermal emissions inventory.

3. Emissions Model Verification - Mobile Sources

In view of uncertainties in determining mobile emissions, an experimental program of emissions model verification is advocated. The uncertainties arise from imprecisions both in the specification of process input parameters and in the accuracy of the postulated input-output relationships.

Recalling previous discussions on the nature of emissions models, we may conveniently define two principal types. In one, the input (I) is known as a function of time (t), and its relationship to the emissions is



SOURCE: Bowman and Biggs, 1972.

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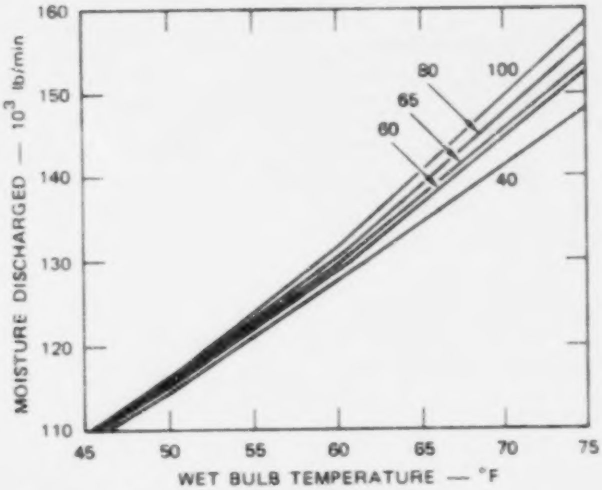
FIGURE 15 PERFORMANCE CURVES FOR COOLING TOWERS GIVING THE EXIT TEMPERATURE AS A FUNCTION OF THE AMBIENT WET BULB TEMPERATURES FOR VARIOUS EXIT RELATIVE HUMIDITIES



SOURCE: Bowman and Biggs, 1972.

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FIGURE 16 PERFORMANCE CURVES FOR COOLING TOWERS GIVING THE MOISTURE DISCHARGE AS A FUNCTION OF THE AMBIENT WET BULB TEMPERATURE FOR VARIOUS EXIT RELATIVE HUMIDITIES

specified by an input-dependent emission factor (EF); the functional form for the specification of the time-dependent emission rate $E(t)$ is

$$E(t) = I(t) \cdot EF(I) \quad .$$

In the second type, the input rate is also unknown and, hence, a time-dependent input factor $(IF(t))$ is also required. The emission rate for this case is then given as

$$E(t) = I \cdot IF(t) \cdot EF(I) \quad .$$

Implicit in these formulations is a knowledge of the spatial distribution of the inputs. Mobile sources (and certain stationary area sources) are especially complex in that the time-dependence of the input factor must be expressed as a function of location.

Thus the so-called emissions model may actually be composed of three components: (1) the apportionment of inputs on a temporal basis, (2) the apportionment of inputs in space, and (3) the relation of emissions to inputs. Similarly, the field (i.e., *in situ*) verification program also must serve to evaluate the emissions model performance in these three areas.

Parameterization of the inputs is particularly relevant to the generation of the mobile emissions. The recommended procedure is to use a statistical database (e.g., ADT) together with continuous measurements of vehicle volume, speed, and mix on selected key links to generate a dynamic link-by-link mobile inventory. Evaluation of the adequacy and representativeness of this procedure should be undertaken. Two methods appear feasible for this purpose: (1) aerial photography, and (2) side-looking aerial radar. The first method could easily provide spatial inventories of vehicle volume and mix by facility type, location, and time of day; less easily obtainable, although possible, is the determination of vehicle speeds. The second method can provide volume and speed distributions, but not vehicle mix. Again, these evaluations are recommended for selected hours, days, and seasons; we do not advocate continuous usage of either method throughout RAPS.

A similar but less difficult problem is the parameterization of temporal and spatial variations of fuel consumption by distributed area sources.

For mobile sources, it is advisable to evaluate parameterization of the inputs and outputs separately; we have already discussed treatment of the former for vehicular sources. For the latter, it remains to verify the representation of time-averaged emissions on a per-link basis. Both average speed and multimodal emission factors can be used, and both are based on emissions during the federal driving cycle (FDC). What is not known are the impacts of deterioration, mix, road grade, drag, and so forth. Model evaluation studies should be undertaken to evaluate the simulation of emissions on a variety of link types (such as freeways, expressways, major arterials, and local feeders) in congested areas. Accurate link measurements of vehicle inputs--volume, mix, speed, and acceleration--will be necessary. Emissions should be determined as averages for 15-minute intervals for all vehicles on the link. A mass budget approach seems most appropriate for this purpose.[29,30] The concept of the mass budget approach is simple, yet its implementation in the field can be difficult--especially when accuracies of 10 to 20 percent are required (see Task B). Simply stated, the fluxes of effluvia into and out of a control volume are measured, and the net flux is equal to the pollutant source or sink within the volume. For the horizontally homogeneous, height-dependent wind field u(z), the mass flux density Q(gm m^{-1} sec^{-1}) through a control volume having zero vertical flux through the top (H) is given by

$$Q = \int_{0}^{H} \chi_1(z)u(z)dz - \int_{0}^{H} \chi_2(z)u(z)dz \quad .$$

Here, $\chi(z)$ is the height-dependent pollutant concentration; the subscripts 1 and 2 refer to the upwind location and the downwind location. Thus, determination of the mass flux density (i.e., emission rate) requires the following:

- Value of the height H.
- Up- and downwind vertical profiles to H of the horizontal wind vector.
- Up- and downwind vertical profiles to H of the pollutant concentration.

For individual roadways, conventional air quality sensors mounted on fixed masts are used to obtain concentration profiles. Remote sensors may be more desirable conceptually because of their path-averaging capabilities, but the state-of-the-art is generally not yet sufficiently advanced for this purpose. One possible exception is the correlation spectrometer which may have application in the evaluation of emission rates from elevated point sources. In this case (i.e., tall stack), the pollutants are emitted into an atmospheric regime where the wind shear is small. Hence, the mass flux equation may be rewritten, where

$$Q \simeq \bar{u} \left\{ \iint \chi_1(z)dydz - \iint \chi_2(z)dydz \right\} .$$

The correlation spectrometer provides the vertical mass loading; crosswind (y) traverses up- and downwind of the plume can thus be used together with the mean transport wind to determine Q (gm sec^{-1}).

In conclusion, we stress the need to evaluate the parameterization of both inputs and subsequent output emissions by models, thus ascertaining the representativeness of the parameters that are input to the inventory and evaluating the precision with which the emissions are subsequently modeled.

4. Resolution of Source Location

A major practical concern in developing an emissions inventory is the degree of resolution required in specifying the location of the point sources. Normally, point sources are resolved to 100 meters in operational inventories; however, subsequent errors introduced in predicting concentrations from such sources may be intolerable in a research study. A 10-meter resolution in source location has been proposed. Before adopting such a specification, it seems desirable to objectively evaluate errors in the predicted concentration field resulting from a mislocation of the source.

Perhaps the most difficult task in the evaluation process is the definition of a meaningful measure of the error (i.e., the difference in predictions with and without an error in the source location). We recognize that this error can be a function of many parameters: source strength, stack height, lateral and longitudinal receptor position, and atmospheric stability. For this evaluation, a worst-case meteorological situation should be used in order to determine the most stringent source-location resolution required. However, a single stability category cannot be used to satisfy this criterion as the worst-case stability for a low stack can differ from that for a tall stack. We have chosen, therefore, two stability regimes--slightly stable (Class E) and slightly unstable (Class C). Source strength and stack height will be seen to be inputs in the assessment methodology, and thus the individual source features are retained. For the impact on receptor location, two alternatives exist: (1) the user is concerned with the error associated with a particular source at one or more specified receptor location (e.g., air quality monitoring site), or (2) the user wishes to evaluate the impact of a particular source throughout the study region. Therefore, we define, as the measure of error, the integral value of the error over both the lateral (crosswind) and longitudinal (downwind) directions; the longitudinal distance may be taken as the distance either to the receptor or to the downwind edge of the study region.

The error in concentration resulting from mislocation of a source is equivalent to that which would result if a receptor were similarly mislocated. We shall take this source location error to be the absolute value of the difference between the concentration χ at the correct location and the concentration χ_E at a point some crosswind distance away. A basic Gaussian plume formulation for atmospheric dispersion is assumed

$$\chi = \frac{Q}{\pi \sigma_y \sigma_z \overline{u}} \exp\left\{ -\frac{1}{2}\left[\left(\frac{y}{\sigma_y}\right)^2 + \left(\frac{H}{\sigma_z}\right)^2\right]\right\}$$

$$\chi_E = \frac{Q}{\pi \sigma_y \sigma_z \overline{U}} \exp\left\{ -\frac{1}{2}\left[\left(\frac{y + \Delta y}{\sigma_y}\right)^2 + \left(\frac{H}{\sigma_z}\right)^2\right]\right\}$$

where

Q = source strength (gm sec^{-1}).

Δy = source location error (m).

y = crosswind direction (m).

H = source height (m).

$\overline{U}$ = effective transport wind speed (m sec^{-1}).

σ_y, σ_z = horizontal and vertical standard deviation of the pollutant distribution, respectively (m).

$\sigma_y = ax^b$.

$\sigma_z = cx^d$.

a, b, c, d = experimentally determined constants dependent on stability conditions.

x = distance along the mean wind direction from the source (m).

We define the integrated measure of error, IE, as

$$(IE) = \int_x \int_y |\chi - \chi_E| \, dydx \quad . \tag{1}$$

Since Q and $\bar{u}$ are constant over the integration, it is possible to define an integrated normalized concentration error, INE, which is independent of these quantities.

$$(IE) = \frac{Q}{\pi u} (INE) \quad . \tag{2}$$

To determine the allowable source location error, Δy, for known values of Q, H, $\bar{u}$, stability and downwind distance, Equation (2) is solved for INE, which is then used to obtain Δy from Figures 17 through 24. However, Equation (2) contains two unknowns, IE and INE. In order to solve Equation (2), a value for IE that represents a tolerable level of concentration error must be defined as a reference. The magnitude of this reference value may be arbitrarily chosen; the error limit presented here is specified on the basis of (1) a reference source strength, $Q_{reference}$, and (2) an allowable source location error for that strength (from which $(INE)_{reference}$ is found using Figures 17 through 24). Thus, IE in Equation (2) becomes IE*, the reference integrated error at downwind distance x for a specific source height and stability.

$$(IE)^* = \frac{Q_{reference}}{\pi \bar{u}} (INE)_{reference} \quad . \tag{3}$$

Combination of Equations (2) and (3), where IE now equals IE*, yields an equation for INE:

$$(INE) = (INE)_{reference} \frac{Q_{reference}}{Q} \quad . \tag{4}$$

The tolerable resolution Δy is then determined (from Figures 17 through 24) on the basis of INE together with atmospheric stability, source height, and the selected downwind distance. Figures 17 through 20 apply to stable atmospheric conditions, while Figures 21 through 24 apply to unstable ones. Source heights of 0, 5, 30, and 100 meters are used in the figures, while Δy values are 5, 15, 30, 60, and 100 meters; interpolation must be used for intermediate values. A step-by-step procedural outline and example follow. Note that a minimum Δy of 10 meters is recommended because of the impact of stack diameter and initial mixing in limiting the occurrence of smaller values.

The determination comprises the following steps:

Step	Task
1.	Select stability category (stable or unstable), stack height (H), downwind distance (x), $Q_{reference}$, and Δy reference.
2.	Using stability, H, x, and Δy reference, determine $INE_{reference}$ from Figures 17 and 24.
3.	Select Q, and using it, $INE_{reference}$, and $Q_{reference}$, solve Equation (4) for INE.
4.	Using stability, H, x, and INE, determine Δy from Figures 17 through 24; let Δy = 10 meters when analysis indicates a lesser value.

For example, we shall use a reference source strength, $Q_{reference}$, of 100 tons per year, i.e., the value given by the Code of Federal Regulations to delineate between treatment of a source as a point or area source. The source location error generally accepted at the present in the most emission inventories is 100 meters, so we shall take Δy as 100 meters. For the specific case of say an 85,000 tons-per-year source strength, a stack height of 30 meters (typical of a power plant stack in Saint Louis), in stable atmospheric conditions, at a receptor point of 10 km downwind of the stack, $INE_{reference}$ is found to be 409 from the appropriate graph—Figure 19. Use of Equation (4) then gives

$$(INE) = (409)\,\frac{100\ \text{tons/year}}{85{,}000\ \text{tons/year}} = 0.48\ .$$

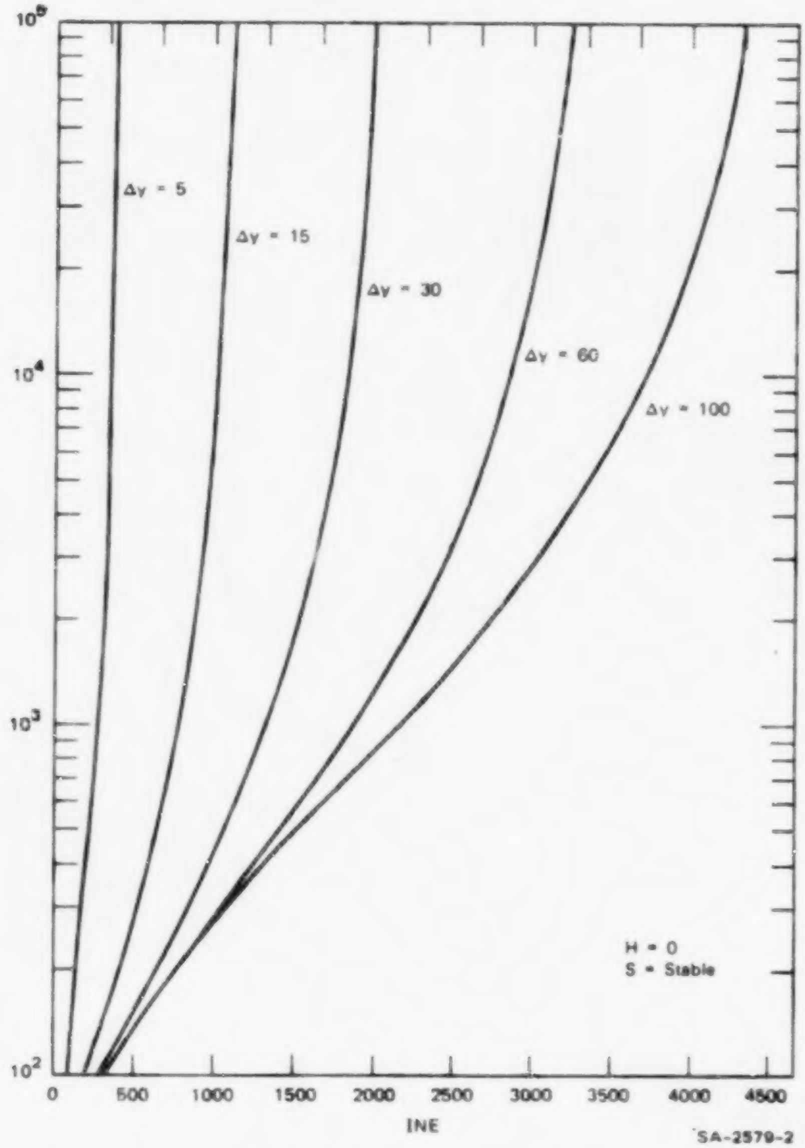

FIGURE 17 VARIATION OF INTEGRATED NORMALIZED ERROR WITH LONGITUDINAL DISTANCE FROM THE SOURCE WHEN SOURCE HEIGHT IS AT THE SURFACE AND ATMOSPHERIC CONDITIONS ARE STABLE

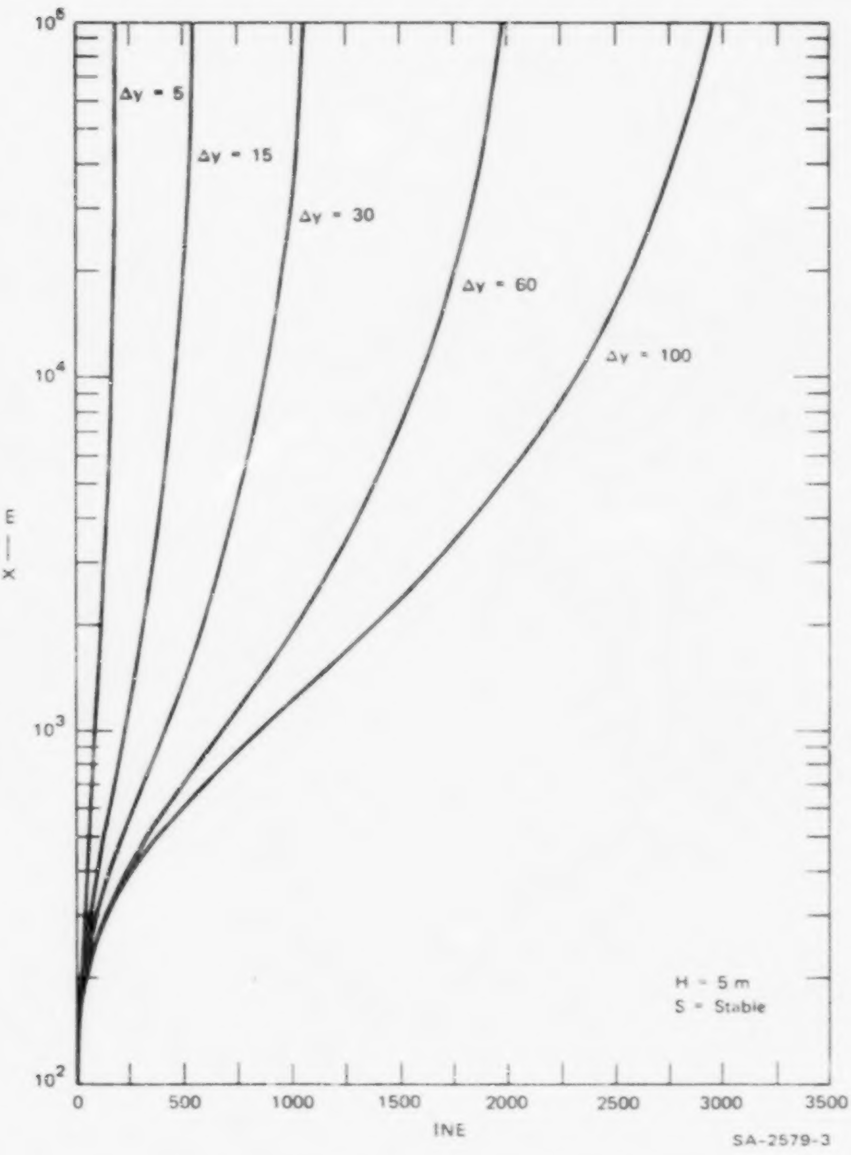

FIGURE 18 VARIATION OF INTEGRATED NORMALIZED ERROR WITH LONGITUDINAL DISTANCE FROM THE SOURCE WHEN THE SOURCE HEIGHT IS FIVE METERS AND ATMOSPHERIC CONDITIONS ARE STABLE

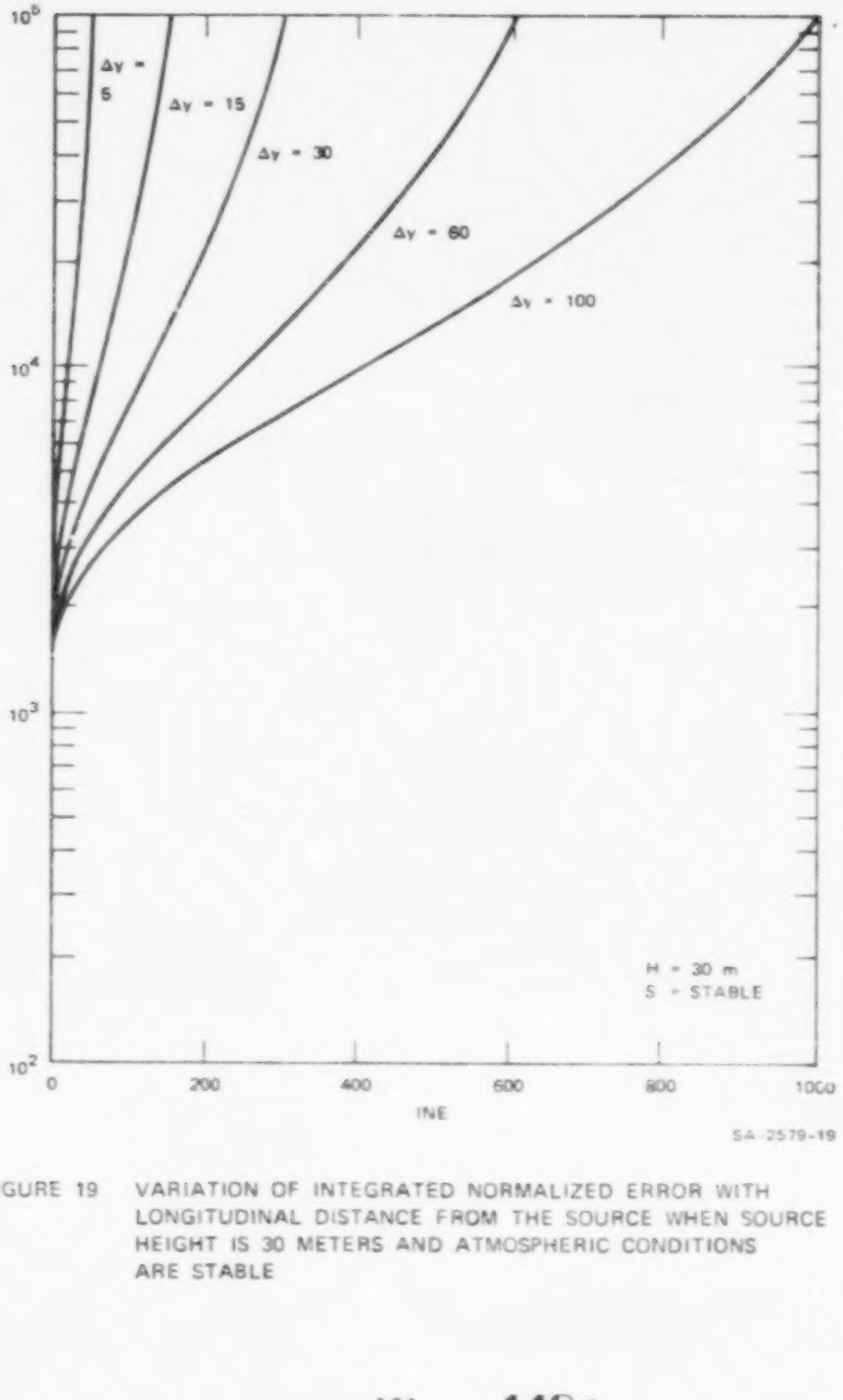

FIGURE 19 VARIATION OF INTEGRATED NORMALIZED ERROR WITH LONGITUDINAL DISTANCE FROM THE SOURCE WHEN SOURCE HEIGHT IS 30 METERS AND ATMOSPHERIC CONDITIONS ARE STABLE

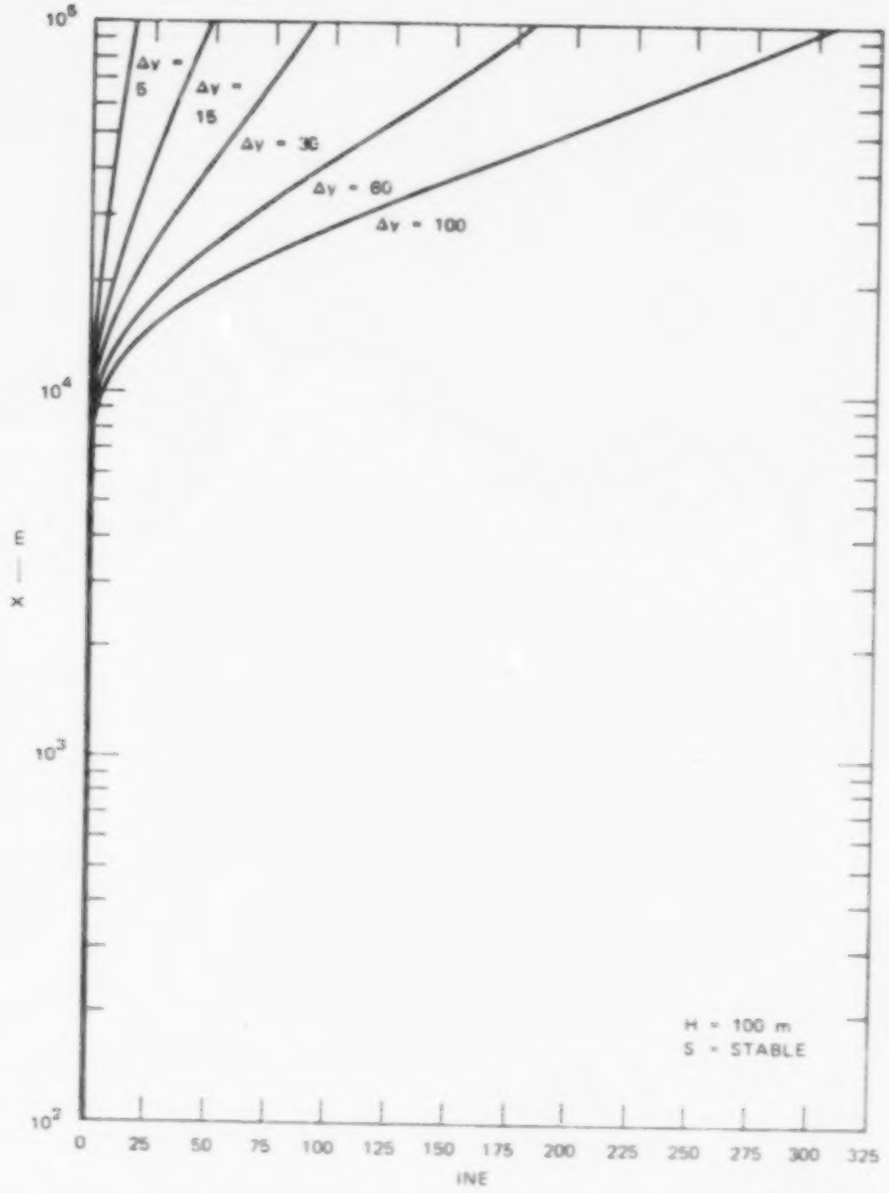

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FIGURE 20 VARIATION OF INTEGRATED NORMALIZED ERROR WITH LONGITUDINAL DISTANCE FROM THE SOURCE WHEN SOURCE HEIGHT IS 100 METERS AND ATMOSPHERIC CONDITIONS ARE STABLE

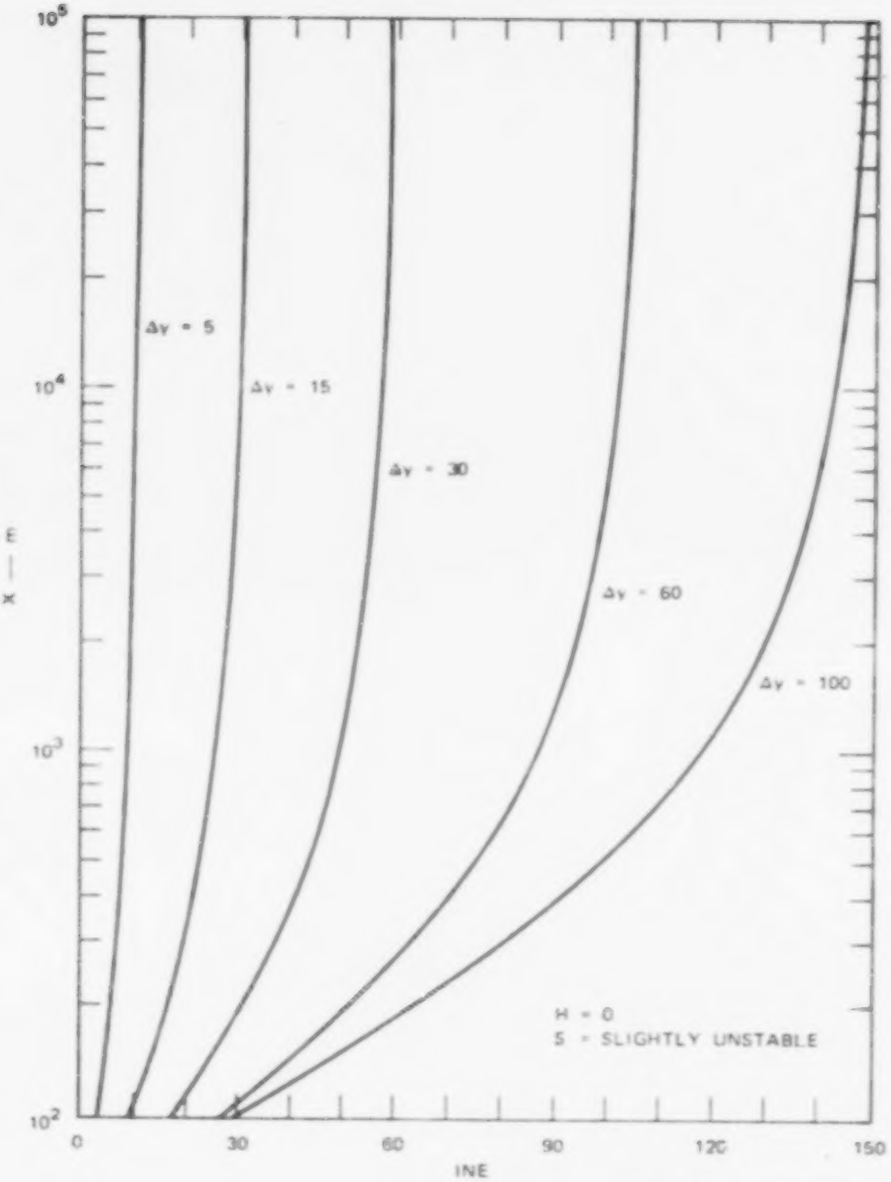

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FIGURE 21 VARIATION OF INTEGRATED NORMALIZED ERROR WITH LONGITUDINAL DISTANCE FROM THE SOURCE WHEN THE SOURCE HEIGHT IS AT THE SURFACE AND ATMOSPHERIC CONDITIONS ARE SLIGHTLY UNSTABLE

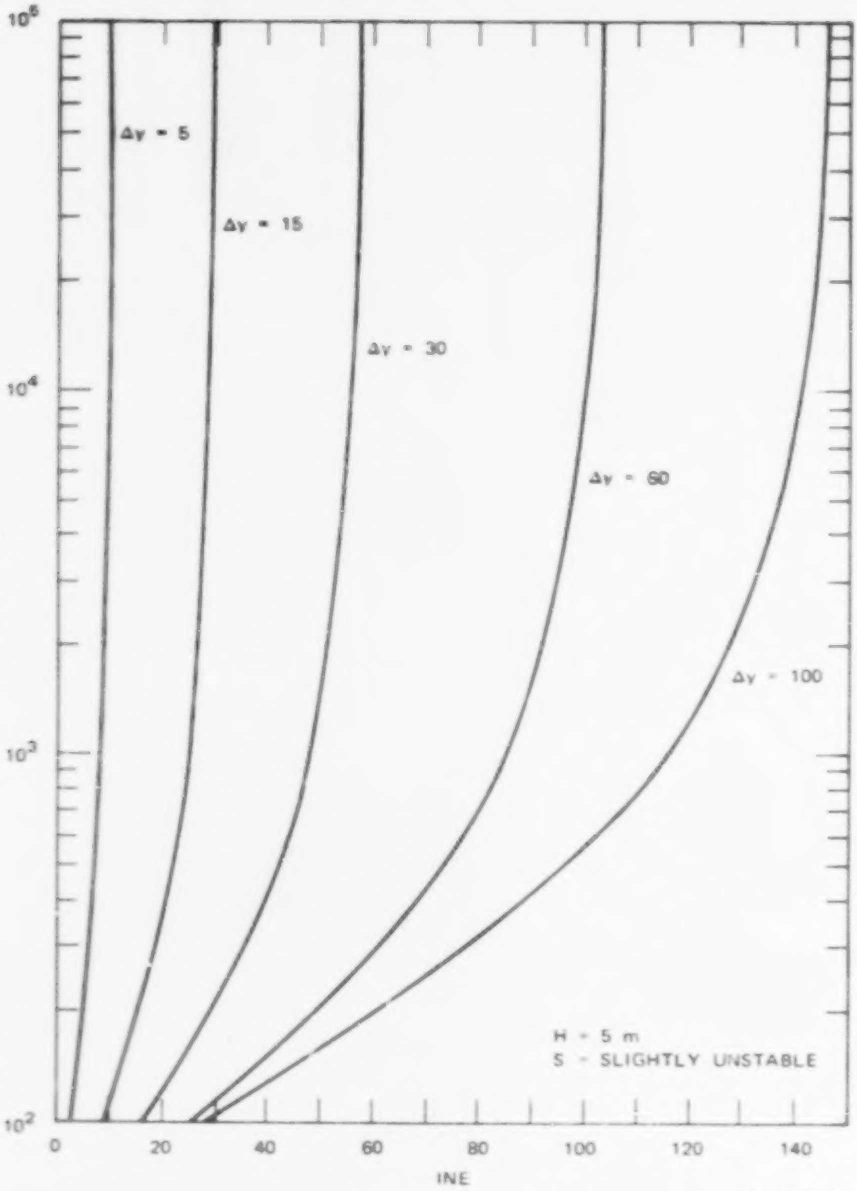

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FIGURE 22 VARIATION OF INTEGRATED NORMALIZED ERROR WITH LONGITUDINAL DISTANCE FROM THE SOURCE WHEN SOURCE HEIGHT IS FIVE METERS AND ATMOSPHERIC CONDITIONS ARE SLIGHTLY UNSTABLE

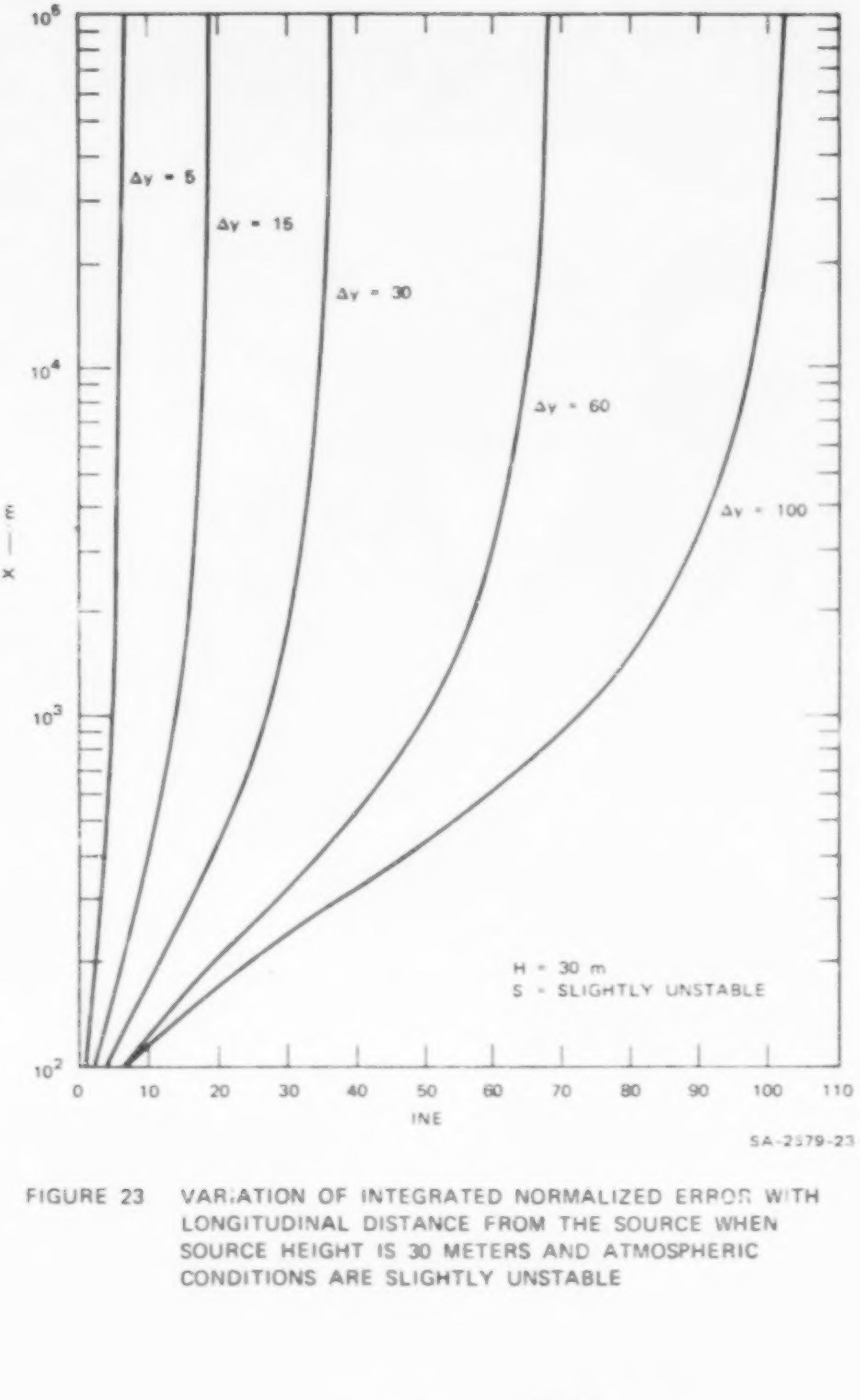

FIGURE 23 VARIATION OF INTEGRATED NORMALIZED ERROR WITH LONGITUDINAL DISTANCE FROM THE SOURCE WHEN SOURCE HEIGHT IS 30 METERS AND ATMOSPHERIC CONDITIONS ARE SLIGHTLY UNSTABLE

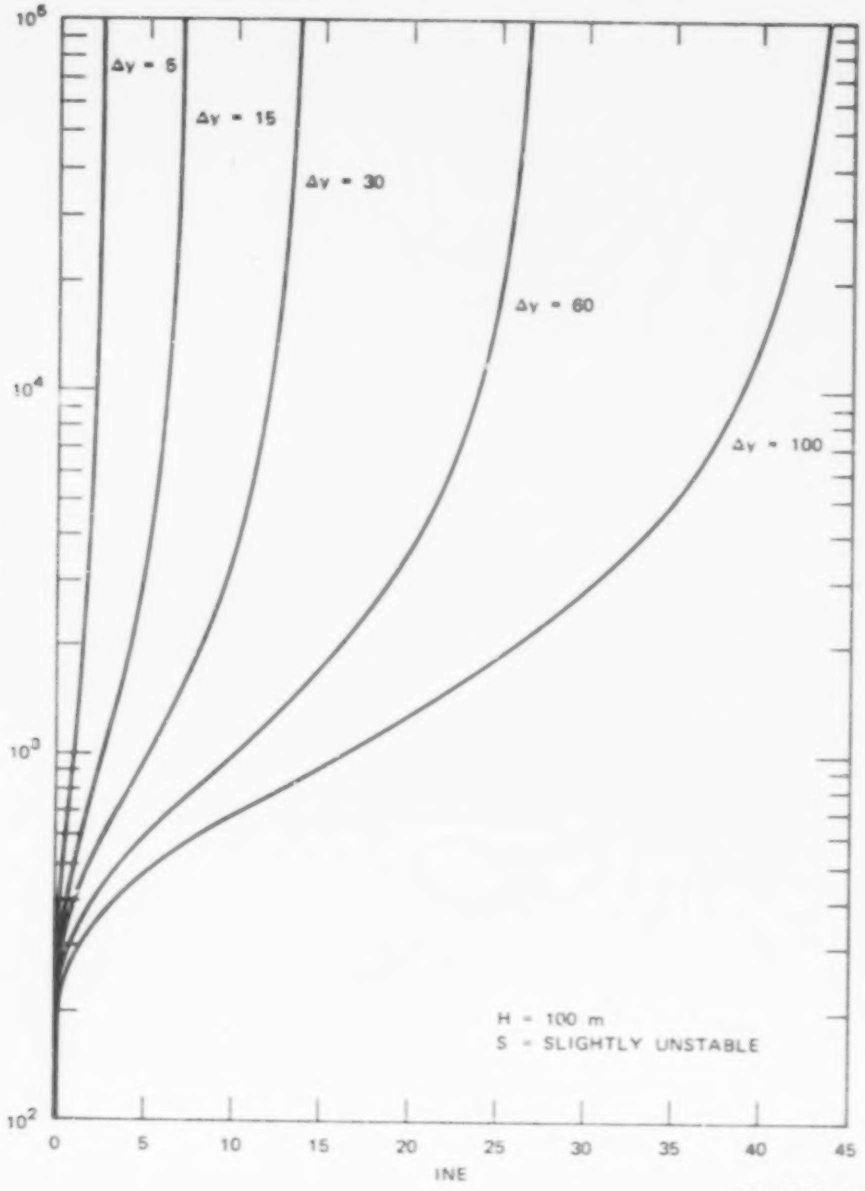

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FIGURE 24 VARIATION OF INTEGRATED NORMALIZED ERROR WITH LONGITUDINAL DISTANCE FROM THE SOURCE WHEN SOURCE HEIGHT IS 100 METERS AND ATMOSPHERIC CONDITIONS ARE SLIGHTLY UNSTABLE

The resulting Δy for this INE, obtained from Figure 19, is very small, suggesting that such a large source must be precisely located, i.e., within 10 meters. With a source strength of 1,000 tons per year and other variables as above, Δy is approximately 18 meters.

A significant feature of this method is its flexibility: The error measure can be taken to most any selected downwind distance or distance interval. In addition, rather than specifying a single resolution required of all stacks, the method yields a recommended spatial resolution for each source based on the stack height and emission rate of the individual source.

C. Consideration of Natural Emissions

Pollutant emissions from natural phenomena require evaluation in the development of an accurate inventory for the region. The natural emissions or production of CO, NO, NO_2, SO_2, nonmethane hydrocarbons, and particulate material in the Saint Louis area are generally small compared with other pollution emissions, but some are large enough to produce a measurable background. There is enough known about the production of the primary pollutants in the biosphere or atmosphere to estimate the production rates or source strengths within a selected area and volume.

For the purposes of RAPS, the Saint Louis source area can be defined as a circle of 35 kilometers radius centered in the business district of Saint Louis. Urban and suburban areas include East Saint Louis, Granite City, Alton, and Belleville (all in Illinois). The area of this circle is about 4000 km^2, the estimated vegetated source area is half of this, or 2000 km^2.

The source strengths of each of the five emission components will be estimated according to its potential production mechanism or mechanisms active in this particular area. Calculated atmospheric concentrations in the Saint Louis area resulting from these emissions must also include background concentrations of the air transported into the Saint Louis air space if a realistic value is to be obtained.

Carbon monoxide is produced naturally in the atmosphere by the oxidation of methane.[31] Atmospheric methane is largely naturally produced from decay of vegetation. The best estimated global production rate is about 2×10^9 tons per year. All of this methane is oxidized in the atmosphere to produce more than 3×10^9 tons of CO annually. The CO, in turn, is oxidized to CO_2. The 4000 km^2 area chosen is 8×10^{-6} of the global area; therefore, the average daily CO production rate is estimated at 70 tons per day.

There are no known natural sources of NO_2 but, NO is generated by vegetation.[32] The global NO natural production rate is 500 x 10^6 tons per year, from an approximate $1x10^8$ km^2 vegetation covered area. If we use the 2000 km^2 area for trees and shrubbery, NO production in the region is about 30 tons per day.

All of the SO_2 produced naturally in the area would result from ozone oxidation of H_2S, again generated by the decay of vegetation. The total annual production of H_2S from the $1x10^8$ km^2 of land areas of the earth is about $70x10^6$ tons.[33] Using the same area ratio as for NO gives an estimated production of 4 tons of H_2S per day. If we consider the 4 tons H_2S to be oxidized in situ, it produces 8 tons of SO_2 per day.

The nonmethane hydrocarbons emitted naturally are all terpenes or isoprene. Pipperton estimates worldwide natural emissions of these substances to be 10^9 tons per year.[34] Hence, 50 tons per day of nonmethane hydrocarbons are produced in the area. The diurnal variation in terpene vapor emission rates is extreme; nearly all of these vapors are released from plants during the hours of daylight. There is also a seasonal variation with a summer maximum and a winter minimum. All of the vapors are released through the foliage. Through the year, the hourly rate of emission will vary from essentially zero (winter night) to about 10 tons per hour (summer daylight maximum).

Natural particulates in the atmosphere of the Saint Louis region are mostly the product of chemical reaction. The oxidation of SO_2 to sulfate and NO_x to nitrate and the formation of polymeric organic particles from terpenes produce most of the background. The only direct natural particulate in the Saint Louis area is dust. The dust loading will vary widely with wind speed. The average dust loading is 5 $\mu g/m^3$. The secondary or condensed aerosol from natural sources adds about 15 to 20 $\mu g/m^3$ to the background.

The yearly global average for dust generated, 200 x 10^6 tons,[33] is reasonable to apply to the Saint Louis area; thus, the average dust production in the Saint Louis region is about 25 tons per day.

Table 27 summarizes the estimated emissions of CO, NO_x, SO_2, H_2S, nonmethane HC, and particulates from natural sources alone and all sources in the Saint Louis region. Carbon monoxide, SO_2 and NO_x production from natural sources is only a small part of the total regional production and can be expected to have little impact on the RAPS studies.

Particulates from natural sources are of marginal significance. Nonmethane HC, on the other hand, may be significant during summer daylight periods. Therefore, we recommend that a procedure be developed for estimating the contribution of natural HC for incorporation in the RAPS Emission Inventory.

Table 27

POLLUTANT EMISSIONS IN THE
SAINT LOUIS AREA*
(Tons/Day)

Type	Natural	Total
CO	70	5100
NO_x	30†	810
SO_x	0	2040
H_2S	4	--
Nonmethane hydrocarbons	50‡	790
Particulate (dust)	25	520

*The area is 4000 km^2 in size.

†Expressed as NO.

‡Maximum rate = 10 tons/hour.

D. Summary of Conclusions and Recommendations

The specific conclusions and recommendations that result from the studies carried out under this task are summarized below:

No existing models adequately meet the requirements of RAPS; to provide emissions data with the necessary high resolution in space and time, it is recommended that

- Direct information be acquired of emissions or of factors determining emissions to the extent possible.
- Where not possible (i.e., for small point sources, and area sources), the most suitable of the existing models should be used in adapted and improved form. Specifically, for stationary sources,

- Direct data from emissions monitoring should be used wherever available (probably only for the largest sources, such as power stations).
- For other large sources, information on hourly fuel consumption rates, process operations, and such, should be obtained and used to derive emissions.
- For small point sources and area sources, modeling procedures based upon the models noted below (but, with refinement of the input data wherever possible) should be used.

Recommended models are

- The Argonne model[2] for hourly SO_2 from distributed residential, commercial, and institutional sources and hourly SO_2 and heat from major point sources.

The Systems Applications, Inc. (SAI) model[1,3] for hourly NO_x and HC from stationary point and area sources.

For automotive mobile sources, we recommend that an average route speed model be used (with a link or line source geometry) supplemented with measured data of traffic flow from fixed sensors on high volume freeways and on selected arterials. The following models are recommended:

- The SAI model[1,3] for hourly CO, NO_x and HC with modified inputs derived from Stanford Research Institute's model[4] for spatial and temporal distribution of vehicle number and speed on a link basis for primary traffic and area basis for secondary traffic.
- Recommended for other mobile sources, are the Geomet model[5] for diurnal emissions from river vessles and railroads and the Northern Research and Engineering model,[6] as revised by Geomet (in preparation), for aircraft emissions.
- For both stationary and mobile sources, the Ontario Department of the Environment (1971) model for Toronto should be referred to for overall guidance and planning methodology.

For microscale studies under the RAPS program the basic inventory will need to be supplemented with special emission inputs. These should be obtained on an experimental or project basis. Detailed data can be acquired from small stationary sources or, for mobile sources, from continuous and detailed monitoring of vehicle behavior in a given area with the application of a multimodal emission model to forecast emissions.

In view of the limitations of existing mobile emission source models and the impossibility of resorting to direct information (as is done in the case with major stationary sources), it is recommended that special steps be taken to improve and verify such mobile emission models. Specifically,

- An experimental evaluation should be made of mobile emissions models to refine the specification of process input parameters and the accuracy of postulated input-output relationships.
- Parameterization of inputs for mobile emissions (statistical database plus continuous measurements of vehicle volume, speed, and mix on key links to generate a dynamic link-by-link inventory) should be verified on a selective basis via aerial photography or side-looking aerial radar or both.
- Temporal and spatial variations of fuel consumption by distributed area sources should be spot metered in fine scale.
- Parameterization of outputs from mobile sources should be evaluated in various models to verify representation of time-averaged emissions on a per-link basis taking into account types of link and the impacts of deterioration, mix, road grade, drag, and so forth.
- Of the pollutant emissions (CO, NO_x, SO_2, H_2S, nonmethane HC, and particulates) from natural phenomena in the Saint Louis area, nonmethane HC may contribute a significant background during summer daylight hours and should be included in the RAPS emission inventory. Suitable procedures to estimate these should be developed early in the RAPS program.
- In the context of the RAPS program, the accuracy of point source locations is best considered in terms of the effect of errors throughout the study area. Accordingly, we propose that a measure of error in source location be defined as the integral value of the error over both the lateral (cross wind) and longitudinal (downwind) directions.

REFERENCES

1. P. J. Roberts, P. M. Roth, and C. L. Nelson, "Contaminant Emissions in the Los Angeles Basin--Their Sources, Rates, and Distribution," Report No. 71, SAI-6, System Applications, Inc. (March 1971).

2. P. J. Roberts et al., "Chicago Air Pollution Systems Analysis Program: A Multiple-Source Urban Atmospheric Dispersion Model," Report No. ES-CC-007, Argonne National Laboratory (May 1970).

3. P. J. Roberts et al., "Extensions and Modifications of a Contaminant Emissions Model and Inventory for Los Angeles," Report No. R73-15, Systems Applications, Inc. (January 1973).

4. F. L. Ludwig et al., "A Practical Multipurpose Urban Diffusion Model for Carbon Monoxide," Project 7874, Stanford Research Institute, Menlo Park, California (September 1970).

5. R. C. Koch and S. D. Thayer, "Validation and Sensitivity Analysis of the Gaussian Plume Multiple Source Urban Diffusion Model," Final Report, Contract No. CPA 70-94, Geomet, Inc. (November 1971).

6. M. Platt et al., "The Potential Impact of Aircraft Emissions Upon Air Quality," Report No. APTD-1085, Northern Research and Development Corporation, Cambridge, Massachusetts (29 December 1971).

7. "RAPS Series No. 1 Study Plan," fifth draft (October 1972).

8. H. M. Benedict, C. J. Miller, and R. E. Olson, "Economic Impact of Air Pollutants on Plants in the United States," Project No. LSD-1056, Stanford Research Institute, Menlo Park, California (November 1971).

9. G. R. Hilst, "Sensitivities of Air Quality Prediction to Input Errors and Uncertainties," Proc. Symp. on Multiple-Source Urban Diffusion Models, Environmental Protection Agency Research, Triangle Park, North Carolina (1970).

10. W. F. Dabberdt and P. A. Davis, "Observations and Analysis of Characteristics and Energy Budget Components of Urban-Rural Surfaces in the Greater Saint Louis Area," Final Report 2322, EPA Contract No. 68-02-1015, Stanford Research Institute, Menlo Park, California (January 1974).

11. "Compilation of Air Pollutant Emission Factors (Revised)," EPA Report No. AP-42 with supplements, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina (1973).

12. D. H. Fair, J. B. Clements, and G. B. Morgan, "SAROAD Parameter Coding Manual," EPA Office of Air Programs, Research Triangle Park, North Carolina (July 1971).

13. G. Ozolins and R. Smith, "A Rapid Survey Technique for Estimating Community Air Pollution Emissions," Public Health Service Publication No. 999-AP-29, U.S. Department of Health, Education, and Welfare, Washington, D.C. (1966).

14. "Guide for Compiling a Comprehensive Emission Inventory (Revised)," APDT-1135, Monitoring and Data Analysis Division, Office of Air and Water Programs, Environmental Protection Agency (1973).

15. "Universal Transverse Mercator Grid," Publication No. TMS-241-8, U.S. Department of the Army, Washington, D.C. (July 1958).

16. J. C. Sturm, "Railroads and Air Pollution: A Perspective," Report No. FRA-RT-73-33, U.S. Department of Transportation Federal Railroad Administration, Washington, D.C. (May 1973).

17. D. B. Turner and N. G. Edmisten, "St. Louis SO_2 Dispersion Model Study--Basic Data," unpublished report (November 1968).

18. L. J. Shieh et al., "The IBM Quality Diffusion Model with an Application to New York City," Report No. G320-3290, Palo Alto Scientific Center, IBM Corporation (June 1971).

19. F. L. Ludwig, A. E. Moon, and R. C. Sandys, "A Preliminary Study of Modeling the Air Pollution Effects from Traffic Engineering Alternatives," APCA Journal, Vol. 23, No. 6, pp. 499-504 (June 1973).

20. C. S. Benson, "Ice Fog: Low Temperature Air Pollution," Report No. UAG R-173, Geophysical Institute, University of Alaska (November 1965).

21. R. L. Mancuso and F. L. Ludwig, "Users Manual for the APRAC-1A Urban Diffusion Model Computer Program," Technical Report, Contract CAPA-3-68 (1-69), Stanford Research Institute, Menlo Park, California (1972).

22. "Compilation of Air Pollutant Emission Factors (Revised)," EPA Report No. AP-42, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina (1973).

23. S. D. Berwager and G. V. Wickstrom, "Estimating Automotive Emissions of Alternative Transportation Systems, Final Report, Contract DOT 05-2004, Department of Transportation Planning, Metropolitan Washington Council of Governments (1972).

24. J. L. Beaton, E. C. Shirley, and J. B. Skog, "Traffic Information Requirements for Estimates of Highway Impact on Air Quality," Interim Report No. FHWA-RD-72-35, California Department of Public Works, Sacramento, California (1972).

25. J. L. Beaton, J. B. Skog, and A. J. Ranzieri, "Motor Vehicle Emission Factors for Estimates of Highway Impact on Air Quality," Report No. CA-HWY-MR 6570825(2) 72-10, California Division of Highways, Sacramento (1972).

26. T. D. Wolksko, M. T. Matthies, and R. E. Wendell, "Transportation Air Pollutant Emissions Handbook," Report No. ANL/ES-15, Argonne National Laboratory, Argonne, Illinois (1972).

27. J. R. Martinez, R. A. Nordsieck, and A. Q. Eschenroeder, "Morning Vehicle-Start Effects on Photochemical Smog," p. 917, Environmental Science and Technology, Vol. 1, No. 10 (1973).

28. W. A. Bowman and W. G. Biggs, "Meteorological Aspects of Large Cooling Towers," Paper 72-128, 65th Annual Meeting of the APCA, Miami Beach, 18-22 June 1972.

29. W. B. Johnson et al., "Field Study for Initial Evaluation of an Urban Diffusion Model for Carbon Monoxide," Report 8563, Stanford Research Institute, Menlo Park, California (June 1971).

30. F. L. Ludwig and W. F. Dabberdt, "Evaluation of the APRAC 1A Urban Diffusion Model for Carbon Monoxide," Report 8563 Contract No. CAPA-3-68(1-69), Stanford Research Institute, Menlo Park, California (February 1972).

31. J. McConnel, M. McElrory, and S. Wofey, "Natural Sources of Atmospheric CO," Science, Vol. 233, No. 187 (1971).

32. L. A. Pipperton, J. B. Worth, and L. Kormrich, "NO_2 and NO in Nonurban Areas," paper 68-122, 61st Annual Meeting, APCA, June 1968.

33. E. Robinson and R. C. Robbins, "Emissions, Concentrations, and Fate of Particulate Atmospheric Pollutants," Final Report 8507, Stanford Research Institute, Menlo Park, California (May 1971).

34. L. A. Pipperton, O. White, and H. E. Jeffries, "Gas Phase Ozone-Pinene Reactions Division Water-Air-and Waste Chemistry," 147th Meeting ACS, Chicago, Illinois, September 1967.

Appendix B

SUMMARY OF EMISSION MODEL REPORTS

CONTENTS

LIST OF ILLUSTRATIONS B-7

INTRODUCTION B-9

I Argonne--Chicago Air Pollution Systems Analysis Program: A Multiple-Source Urban Atmospheric Dispersion Model . . B-11

II Argonne--Transportation Air Pollutant Emissions Handbook B-19

III ESSA--The Diurnal and Day-to-Day Variations of Fuel Usage for Space-Heating in Saint Louis, Missouri B-27

IV FHA--APRACMOD, Modification of APRAC-1A B-31

V Free University of Berlin--Numerical Simulation of Temporal and Spatial Distributions of Urban Air Pollution Concentration B-35

VI GE--Study of Air Pollution Aspects of Various Roadway Configurations B-39

VII GRC--Evaluation of a Diffusion Model for Photochemical Smog Simulation B-47

VIII Geomet--Validation and Sensitivity Analysis of the Gaussian Plume Multiple-Source Urban Diffusion Model . . B-49

IX IBM--The IBM Air Quality Diffusion Model with an Application to New York City B-61

X IBM--Source Emissions and the Vertically Integrated Mass Flux of Sulfur Dioxide Across the New York City Area B-67

XI Metropolitan Washington Council of Governments--Estimating Auto Emissions of Alternative Transportation Systems B-71

XII National Air Pollution Control Administration--Saint Louis SO_2 Dispersion Model Study, Basic Data . . . B-77

XIII National Air Pollution Control Administration--Emission Factors B-81

XIV NR&E--The Potential Impact of Aircraft Emissions Upon Air Quality B-87

XV Ontario Department of the Environment--Information System Descriptive Manual B-93

XVI Pacific Environmental Services--Controlled Evaluation of the Reactive Environmental Simulation Model B-97

XVII Rutgers University--Comparison of Air Pollution from Aircraft and Automobiles B-103

XVIII Sacramento Regional Area Planning Commission--General Inventory of Air Pollution Sources and Emissions B-107

XIX SRI--A Practical, Multipurpose Urban Diffusion Model for Carbon Monoxide B-109

XX SRI--Procedures for Estimating Highway User Costs, Air Pollution, and Noise Effects B-117

XXI SRI--A Preliminary Study of Modeling the Air Pollution Effects from Traffic Engineering Alternatives B-125

XXII SAI--(1) Contaminant Emissions in the Los Angeles Basin--Their Sources, Rates, and Distribution. (2) Extensions and Modifications of a Contaminant Emissions Model and Inventory for Los Angeles B-131

XXIII SDC--Development of a Simulation Model for Estimating Ground Level Concentrations of Photochemical Pollutants B-145

XXIV TSC--Sensitivities of Air Quality Prediction to Input Errors and Uncertainties B-149

XXV TRW--Prediction of the Effects of Transportation Controls on Air Quality in Major Metropolitan Areas . . B-153

XXVI University of Alaska--Ice Fog: Low Temperature Air Pollution B-161

XXVII University of California (Davis)--The Impact of Highways on Air Quality B-165

XXVIII USWB--A Simple Diffusion Model for Calculating Point Concentration from Multiple Sources B-167

ILLUSTRATIONS

B-1 Flow Diagram for Calculation of Pollution Levels B-18

B-2 Speed Adjustment Factors for Hydrocarbon Exhaust Emission Factors and Carbon Monoxide Emission Factors . . B-23

B-3 Profile of Carbon Monoxide Versus Traffic Flow Rate at FDR Drive B-40

B-4 Relationship Between Vehicular Pollution Factors Taken at Exhaust Plane and Traffic Speed B-42

B-5 Flow Chart of Auto Emissions Model B-73

B-6 Exhaust Emission Flow Diagram B-84

B-7 Flow of Source Subroutine B-101

B-8 Automobile Hydrocarbon and Carbon Monoxide Emissions Added per 1,000 Stops B-120

B-9 Automobile Hydrocarbon and Carbon Monoxide Emissions per 1,000 Miles of Driving at Uniform Speed B-120

B-10 Automobile Emissions Added from Speed Changes per 1,000 Vehicle-Miles B-121

B-11 Factor to Convert Reference Year Emissions to Emissions in Year Y B-122

B-12 Relationship Between Carbon Monoxide Emissions and Steady-Speed Driving B-127

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INTRODUCTION

In this Appendix we have reviewed and summarized twenty-seven reports on the treatment and parameterization of man-made emissions. These summaries are intended to provide the potential user with a concise overview of the scope and content of each of the models. Each summary identifies the author and his or her affiliation, includes the author's abstract, and provides a synopsis of the emission model methodology together with a statement of the model's format and availability.

For convenience, the reports are listed alphabetically by affiliation. The depth and merit of the various models are reflected in the summaries. While our review is extensive, it should not be interpreted as all inclusive. Many reports were reviewed initially and later deleted from this final listing either because they were of no direct use to RAPS or because the methods they contained were more appropriately documented or developed elsewhere.

I ARGONNE NATIONAL LABORATORY

Chicago Air Pollution Systems Analysis Program: A Multiple-Source Urban Atmospheric Dispersion Model. J. J. Roberts, E. J. Croke, A. S. Kennedy, J. E. Norco, and L. A. Conley, Argonne Natl. Lab. Rept. No. ES-CC-007, prepared for Chicago Dept. of Environmental Control and National Air Pollution Control Administration, May, 1970.

A. Author's Abstract

This report is a comprehensive documentation of the dispersion-model development phase of the Chicago Air Pollution Systems Analysis Program. A multiple-source, urban atmospheric dispersion model has been developed which described transients such as morning transitions in atmospheric stability and mixing layer height. The dispersion model has been validated by comparison with over 10,000 hourly averages of sulfur dioxide monitored by the Department of Environmental Control of the City of Chicago. For example, the model accounts for 50% of the variance in 6-hr averages of observed data and 70% of the variance in 24-hr averages. Of particular significance in the capability of the model to describe "area sources" as volumetric clouds of pollutant and thus to evaluate the effect of these sources on dose points within, as well as external to, the area.

The atmospheric transport kernel in the model describes the instantaneous release (delta function) of pollutant, advection according to piecewise constant hourly wind vectors, and Gaussian diffusion about the centroid. Continuous plumes are simulated by integration in time of this point-source Green's function.

This report details the transport theory and all other computerized algorithms that influence the dispersion problem and presents statistical results of extensive validation studies.

B. Summary

An inventory of average hourly emissions of sulfur dioxide was developed for power plants and industrial, residential, commercial, and institutional sources in the Chicago area. Hourly SO_2 emissions from power plants were derived from actual power output logs; hourly emissions from other sources were obtained through reduction of annual fuel-use data according to seasonal and diurnal patterns. Major emitters were considered individually as point sources, with the remaining emissions grouped into area sources.

1. Treatment of Area Sources

The area source overlay grid is input to the model. It is specified by five parameters: the x, y coordinates of the origin, the number of grid squares in the x and y directions, and the length of the side of each grid square. The grid used in the validation computation consisted of 1.0x1.0-mile squares at the center of the array, with surrounding 2.0x2.0-mile, then 4.0x4.0-mile grid squares.

Representative pollutant emission rates and stack heights are assigned to each grid square for each source: (1) low-rise space heaters; (2) high-rise space heaters; and (3) industry.

a. Low-rise Residential and Commercial Emissions

Hourly emissions from low-rise residential and commercial sources are assumed to be proportional to the number of heating degree days, with a fixed fraction of annual emissions uniformly prorated to hot water heating. The heating cycle is assumed to occur between the hours TON and TOFF, with emissions equal to the hot water rate at all other times. A "janitor function" is synthesized to account for the greater than usual fuel demand during the first two hours of the heating day. Hourly emissions are given by

$$Q_{heating} = \frac{Q_{annual} (1-PCTHW) (65-TEMP) TE}{DDAVG (TONOFF)} \qquad \begin{array}{l} TEMP < 65^{\circ}F \text{ and} \\ TON \leq \text{time of day} \\ \quad < TOFF \end{array}$$

$$Q_{hot\ water} = \frac{Q_{annual} (PCTHW)}{8760}$$

$$Q_{total} = Q_{heating} + Q_{hot\ water}$$

where DDAVG = average number of degree days/year

PCTHW = fraction of annual fuel used for hot water

TEMP = hourly average temperature

TONOFF = TOFF - TON + 1

$$TE = \text{janitor function} = \begin{cases} 1.5 & TON \leq \text{time of day} < TON + 1 \\ 1.0 & TON + 1 \leq \text{time of day} < TOFF \end{cases}$$

All moderate-sized residences were assigned a stack height of 50 feet.

b. High-rise Residential, Commercial and Institutional Emissions

These emissions are estimated using the above method, but with TON = 1 and TOFF = 24. Physical stack height was assumed to be 200 feet.

Industrial Emissions. Industrial area source emissions are distributed uniformly over the calendar year:

$$Q_{hourly} = \frac{Q_{annual}}{8760}$$

2. Treatment of Point Sources

a. Power Plant Emissions

Actual hourly power output (MW) from Chicago power plants was used in the validation study of the model. The following power plant emission algorithms are proposed as the production version of the program.

For each season of the year, a graph is made of peak daily load versus average daily temperature. From these graphs the peak load is estimated as a linear function of temperature. Several daily charts of system load versus hour of the day, within a given season, are superimposed. Weekday patterns for summer and winter result, with spring and fall having two weekday patterns each that are distinguished by average daily temperature. Since little weekend data are usually available, a typical weekend pattern is used for all seasons. The patterns are stored as data statements containing 24 numbers, one for each hour of the day. Given the average daily temperature, the day of the week, and the season of the year, the hourly system load is calculated by subtracting the data statement of the appropriate hour from the peak load obtained from the graph of peak load versus temperature.

If individual unit load is plotted against total system load, functional relationships of the form

$$U = \begin{cases} b_1 & S < a_1 \\ b_1 + (b_2 - b_1)\left[\dfrac{S - a_1}{a_2 - a_1}\right] & a_1 < S < a_2 \\ b_2 & S > a_2 \end{cases}$$

where U = individual unit load

S = system load

a_1, a_2, b_1, b_2 = coefficients derived from the graph

can be formulated for each unit, making it possible to obtain individual unit load from the previously calculated system load.

Graphs of utility company data give the variation of unit load with thermal input, and coefficients describing this variation are derived. Thermal input is given by

$$T = AL + B$$

where T = thermal input

L = unit load

A,B = derived coefficients

Hence, emission rates are determined:

$$SO_2 \text{ from coal } (\text{lb/hr}) = \frac{[T(\text{therms/hr})]\,[10^5 \text{ BTU/therm}]\,(\text{avg. annual \% coal used}]}{[12{,}000 \text{ BTU/lb}]\,[2000 \text{ lb/ton}]} \cdot \frac{[38.0]\,[\text{\% sulfur of coal}]}{[12{,}000 \text{ BTU/lb}]\,[2000 \text{ lb/ton}]}$$

$$SO_2 \text{ from oil } (\text{kgal/hr}) = \frac{[T(\text{therms/hr}]\,[10^5 \text{ BTU/therm}]\,[\text{avg. annual \% oil used}]}{[18{,}000 \text{ BTU/lb}]\,[8000 \text{ lb/kgal}]} \cdot \frac{[157]\,[\text{\% sulfur of oil}]}{[18{,}000 \text{ BTU/lb}]\,[8000 \text{ lb/kgal}]}$$

The thermal emission rate is given by

$$\text{thermal emission rate} = 0.12\ T$$

To divide total thermal and SO_2 emission rates among the stacks, the percent of effluent handled by each stack is applied to the total rate.

b. Industrial Emissions

[illegible] largest industrial source emitters are treated as point sources, with the remaining emissions aggregated into uniformly distributed square mile area sources. Plants in this category are assumed to have a stack height of 150 feet.

A detailed analysis of the diurnal, weekly, and seasonal operating patterns for each plant was performed, yielding factors by which the maximum process load is multiplied to obtain the process load at a given time.

$$L^P = \left(\begin{matrix}\text{shift weighting}\\ \text{factor}\end{matrix}\right)\left(\begin{matrix}\text{monthly weighting}\\ \text{factor}\end{matrix}\right) L^P_{MAX}$$

where L^P = process load

L^P_{MAX} = maximum process load

Shift factors are tabulated for weekdays, Saturdays, and Sundays or special holidays for each of the three shifts, 0000-0800, 0800-1600, and 1600-0000 local time. Monthly factors account for seasonal variations.

The space-heating thermal load is assumed to be linearly related to temperature.

$$L^s = L^s_{MAX} \left[\frac{55-T}{65}\right] \qquad -10 \le T \le 55$$

where L^s = space-heating thermal load

L^s_{MAX} = maximum space-heating thermal load

T = temperature

The total thermal load is

$$L = L^s + L^p = L^c + L^o$$

where L equals total thermal load and L^c and L^o are the portions of the thermal load due to coal and oil, respectively.

$$SO_2^{\ c}\ (\text{lb/hr}) = \frac{[L^c\,(\text{therms/hr})]\ [10^6\ \text{BTU/therm}]\ [36.8]\ [\%\ \text{sulfur of coal}]}{[12{,}000\ \text{BTU/lb}]\ [2000\ \text{lb/ton}]}$$

$$SO_2^{\ o}\ (\text{kgal/hr}) = \frac{[L^o\,(\text{therms/hr})]\ [10^6\ \text{BTU/therm}]\ [157]\ [\%\ \text{sulfur of oil}]}{[18{,}000\ \text{BTU/lb}]\ [8000\ \text{lb/kgal}]}$$

When a dual-fuel interruptible plant is receiving natural gas, the SO_2 emissions are correspondingly reduced.

Heat emissions are assumed to be 15% of the thermal input.

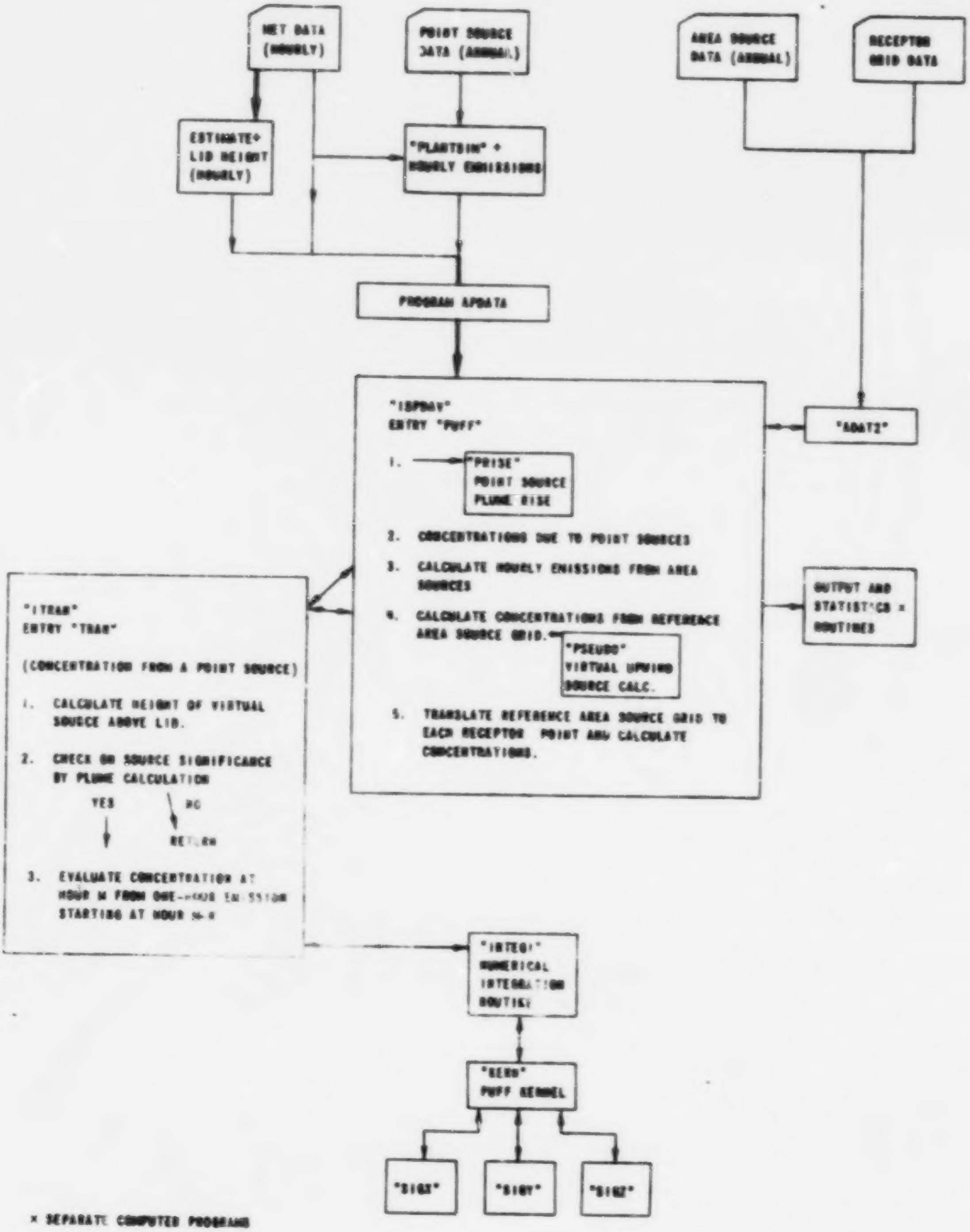
Heat and sulfur dioxide emissions from a plant are apportioned to its stacks by weighting the total emission rates by the percentage of effluent handled by each stack.

c. Additional Sources

Annual emission information from several additional point sources was stored in a subroutine of the dispersion model and prorated by appropriate program statements. These emissions were distributed using one of three source patterns: (1) uniform proration of annual output; (2) 24-hour degree day response, with 20% of fuel use prorated uniformly for hot water; and (3) a special diurnal pumping station pattern. The pumping station pattern allowed two levels of output, a high level between the hours 0600 and 2200, and a low level, about one-third of the daytime emission rate, at all other times.

C. Model Availability

A program listing of the Argonne emissions model is included in the report.


MET DATA (HOURLY)
POINT SOURCE DATA (ANNUAL)
AREA SOURCE DATA (ANNUAL)
RECEPTOR GRID DATA
ESTIMATE+ LID HEIGHT (HOURLY)
"PLANTBIN" + HOURLY EMISSIONS
PROGRAM APDATA
"ISPDAV"
ENTRY "PUFF"
1.
"PRISE" POINT SOURCE PLUME RISE
2. CONCENTRATIONS DUE TO POINT SOURCES
3. CALCULATE HOURLY EMISSIONS FROM AREA SOURCES
4. CALCULATE CONCENTRATIONS FROM REFERENCE AREA SOURCE GRID.
"PSEUDO" VIRTUAL UPWIND SOURCE CALC.
5. TRANSLATE REFERENCE AREA SOURCE GRID TO EACH RECEPTOR POINT AND CALCULATE CONCENTRATIONS.
"ADAT2"
OUTPUT AND STATISTICS × ROUTINES
"ITRAN"
ENTRY "TRAN"
(CONCENTRATION FROM A POINT SOURCE)
1. CALCULATE HEIGHT OF VIRTUAL SOURCE ABOVE LID.
2. CHECK ON SOURCE SIGNIFICANCE BY PLUME CALCULATION
YES
NO
RETURN
3. EVALUATE CONCENTRATION AT HOUR N FROM ONE-HOUR EMISSION STARTING AT HOUR N-K
"INTEGI" NUMERICAL INTEGRATION ROUTINE
"KERN" PUFF KERNEL
"SIGX"
"SIGY"
"SIGZ"

× SEPARATE COMPUTED PROGRAMS

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FIGURE B-1 FLOW DIAGRAM FOR CALCULATION OF POLLUTION LEVELS

II ARGONNE NATIONAL LABORATORY

Transportation Air Pollutant Emissions Handbook. T. D. Wolsko, M.T. Matthies, and R. E. Wendell, Argonne National Laboratory, Argonne, Illinois, July, 1972.

A. Author's Abstract

The objective of this report is to describe a procedure that can be used to quantify the air pollutant emissions (carbon monoxide, hydrocarbons, nitrogen oxides) from transportation sources. The report is designed to enable someone not familiar with air pollution problems from transportation systems to quantify such emissions with the aid of the background information, emission data, computer program descriptions, and manual calculation procedures contained herein. Although emissions from transportation vehicles are not completely understood, the state-of-the-art of measuring air pollutant emissions from transportation sources is presented. This report will be revised if and when a more complete understanding of emissions from transportation sources evolves.

Section 1 provides a brief background on the sources of air pollution from transportation vehicles. The basic emission data used to calculate transportation emissions are described in Section 2. Two computer programs that can be used to calculate emissions are described in Section 3. The first program, TREFACT, calculates emission factors for widely varying vehicle characteristics and transportation system operation. The second program, TREMISS, uses regional transportation simulation data to calculate emissions for large transportation networks. Complete source listings of both programs are given in Appendix A.

Manual emission calculation procedures are illustrated by means of sample problems in Section 4. These procedures are designed to provide

a simple method for calculating air pollutant emissions from roadways. A fairly complete set of emission factors is tabulated in Appendix B, so that transportation emissions can be calculated without using either of the computer programs.

B. Summary

Two computer programs were written to relieve the environmental impact analyst of the emission calculation burden. The first program, TREFACT, calculates the emission rates for vehicles or mixes of vehicles based on vehicle usage (speed, vehicle miles, type of trip). The second program, TREMISS, was developed to calculate emissions for the complex traffic simulation grid used by urban regional transportation planners. The outputs from a typical regional traffic simulation model (origins, vehicle miles, speed) and TREFACT outputs are used to calculate grid-dependent emissions for the entire urban region. A detailed description of each of these programs is provided, along with input descriptions and sample problems. Complete listings of both programs are contained in an appendix.

The computer programs are used to calculate grid-dependent emissions for large urban transportation networks. A method for manually calculating air pollutant emissions from transportation sources is described in another section of the report. This method is designed to calculate emissions from individual transportation links (e.g., highways).

The emission factors calculated by TREFACT are for the standardized urban and rural speeds. TREMISS has speed adjustment data to modify the emission factors for the speed-dependent transportation network. The speed adjustment curves from the figures accompanying this summary have been transformed into a set of linear equations that will be used to adjust the emission calculations for individual roadways. Urban and rural speed adjustment factors should be used with urban and rural emission factors, respectively. It should be remembered that this speed adjustment data are representative of typical traffic and does not represent free-flowing traffic at that average speed.

TREFACT calculates emission factors for transportation systems with widely varying vehicle types and operating conditions. Emission factor can be calculated for any year between 1960-1990 for six classes of vehicles. A vehicle-class-weighted emission factor is also calculated. Options are available to include the effects of cold-start operation, retrofitting control devices on pre-1968 vehicles (Class 1 only), and consideration of diesel-powered vehicles.

Urban regional transportation planning involves an enormous computer traffic simulation system. The typical Chicago Area Transportation Study (CATS) traffic simulation network has approximately 1,800 transportation activity grids which cover the eight-county Chicago metropolitan area. A computer program was written to calculate grid-dependent air pollutant emissions (CO, HC, NO_x) from transportation sources for the CATS planning area. This program, TREMISS, uses output data files from the CATS traffic simulation model, but data from any traffic simulation program can be used.

Regional traffic simulations are quite costly and there may not always be data available for the study year. Therefore, TREMISS has the additional capability of linearly interpolating between simulation output data for two study years. This is extremely helpful when traffic data is not available for a particular year. TREMISS is structured to interpolate between 1965 and 1985 simulations for any intervening year.

Emissions can be calculated for each grid using either one set of "weighted" emission factors or six sets of emission factors, one for each class of vehicles. (Diesels [Class 6] may or may not be used in the calculation.) Additionally, the complete set of grids may be grouped into any number of subsets. Each such subset has its "own" set of emission factors. However, the mixing of "weighted" and "class" emission factors is not permitted.

Emission summaries for each grid and the totals for all grids are the major outputs. If class-dependent emission factors are used, summaries by class are also given. Emission summaries for any specified set of grids representing a county, municipality, or problem area (e.g., Cook County, Chicago, Chicago Business District) can also be calculated.

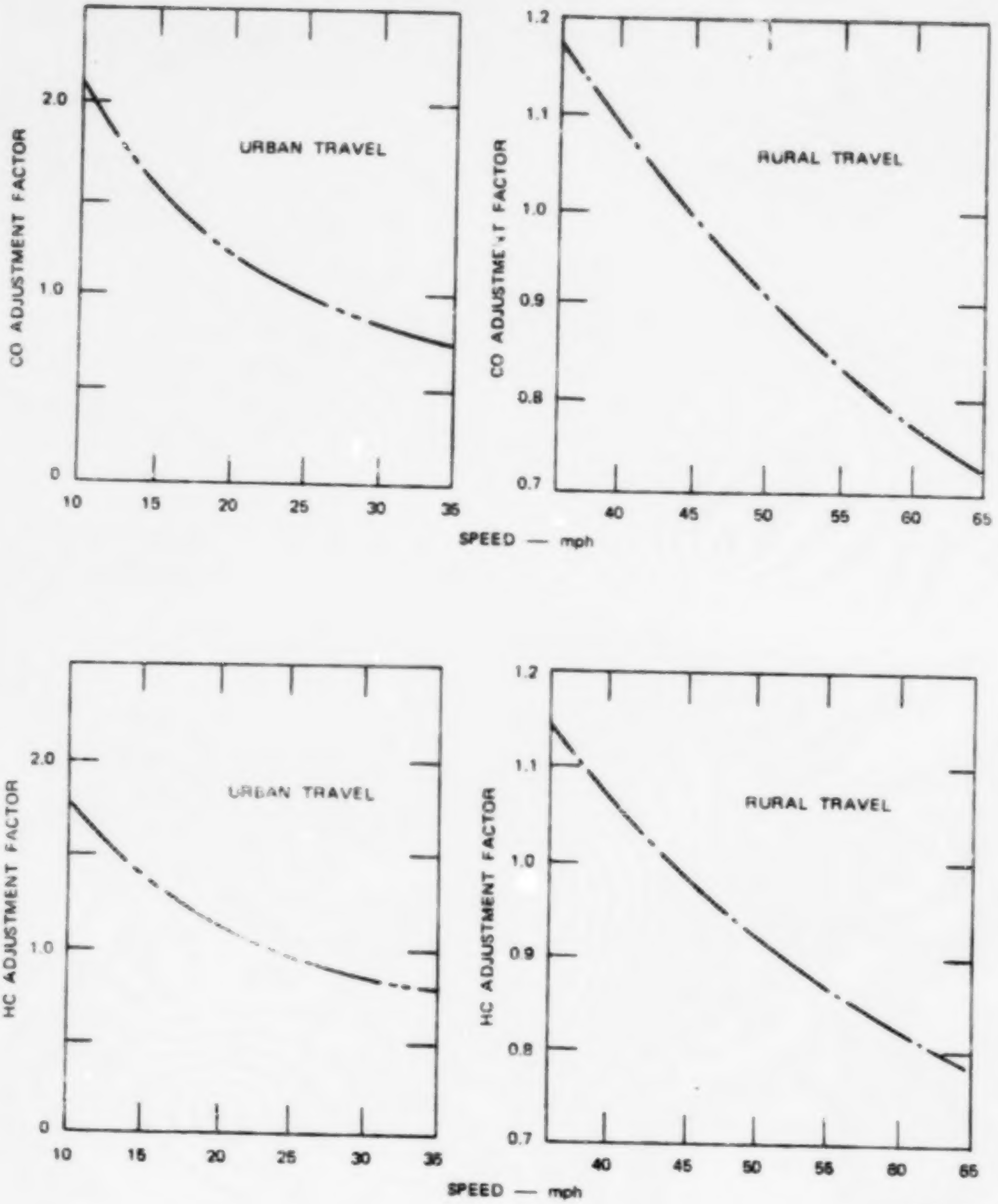

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FIGURE B-2 SPEED ADJUSTMENT FACTORS FOR HYDROCARBON EXHAUST EMISSION FACTORS AND CARBON MONOXIDE EMISSION FACTORS

EMISSION MODELS CHECKLIST

Input Data Requirements

	Within Program	User Supplies	From AP-42	Proxies/Comments
Vehicle Emission Factors				
-By model year	x	x	x	Factors available in report for use as desired
-By size class	x	x	x	
-By power plant	x	x	x	
-Deterioration factor	x	x	x	
Vehicle Operating Modes				
-Hot/cold start	x	x	NP	
-Route average	x	x	x	
-Link average	NP	NP	NP	
-Mode-by-mode	NP	NP	NP	
Traffic Features				
-Vehicle mix	x	x	x	
-Engine operating time	NP	NP	NP	
-Vehicle miles traveled	NP	NP	NP	
-Fuel consumed	x	NP	NP	For heavy duty 'truck calculations
Spatial Distribution				
-Links			NP	
-Grinds	x	x	NP	
-Area			NP	

NP = No provision

Output Available

Pollutants	
-CO	Yes
-HC	Yes
-NO_x	Yes
-Particulates	No

Availability of Program Documentation

	Yes	No
Included in report	x	
Referenced in report	x	
Language	FORTRAN ; PL/1	
Equipment	IBM	

Validation/calibration: Chicago area and EPA data

Time resolution: Hourly (peak/off-peak); daily

Spatial resolution: Subareas; grids

III AIR RESOURCES FIELD RESEARCH OFFICE, ESSA

The Diurnal and Day-to-Day Variations of Fuel Usage for Space-Heating in St. Louis, Missouri. D. B. Turner, Atmospheric Environment, 1968.

A. Author's Abstract

Data on the wintertime emissions of SO_2 from residential and commercial space-heating sources by 2-hr periods were needed for use in a diagnostic dispersion model. Analyses were made of hourly steam-output data from a centralized heating plant and hourly gas-sendout data for December 1964 at St. Louis, Mo., to determine dependence upon temperature and other factors. Methods were then developed to determine the rate of fuel use from residential and commercial space-heating sources for each hour of the day from values for the hourly temperature, the hour of the day, and the day of the week. Relations developed from December 1964 data were tested on data for January and February 1965.

B. Summary

1. Description of Algorithm

A mathematical representation of the diurnal and day-to-day variations of fuel consumption resulting from residential and commercial space heating was developed for St. Louis, Missouri. Available data included hourly temperatures and hourly gas and steam output rates. Steam output rates are taken as representative of commercial sources, and gas send-out rates are taken as representative of residential sources.

To obtain equations relating daily output and daily temperature, graphs were constructed to give the least-squares linear regressions for weekdays and weekends. For weekdays, 20 data pairs were used to give

$DS = 8.40 - 0.1078\ DT$

$DG = 30.00 - 0.3478\ DT$

where DS = daily steam output rate

DG = daily gas send-out rate

DT = daily temperature

The effect of short-term temperature variation on the diurnal cycle of space heating was investigated by determining the deviation of the hourly temperature from the daily value for both gas and steam, and then averaging these deviations for each hour for all weekday data. Plots of both gas and steam deviations versus temperature deviation were made, and the finite difference forms of the daily send-out equations were applied to give output deviations with zero temperature deviation. These hourly values, calculated for weekdays, Saturdays (only four data days were used) and Sundays (only five data days were used), represent diurnal variation due to all causes other than temperature.

To make these variations applicable to other space heating sources, the values were divided by the slope of the regression line, thus converting to units of temperature. Saturday and Sunday values were adjusted so that the same total daily heat is required for a day with the same daily temperature, regardless of whether it is a Saturday, Sunday, or weekday.

Hourly steam output or gas-send-out is given by

$A = a+b(T+H)$

where A = hourly output

a,b = regression constants in daily output equations

T = hourly temperature

H = diurnal value (calculated above) for appropriate hour of day, day of week, gas or steam

It is assumed that no lag time exists between a change in temperature and its effect on space heating requirements.

2. Validation

The above equation was derived from data recorded in St. Louis during the month of December, 1964, and was used to calculate hourly output for January and February, 1965, for comparison with actual data. Error was measured in degrees Farenheit. For steam, 71% of the calculated values were less than 6°F in error, and 95% were less than 12°F in error. For an hour with a temperature of 30°F, an error of 12°F results in about 25% error in steam output.

Overall, 80% of the calculated data were within ± 7°F of the actual values. The author states that this degree of accuracy is commensurate with the accuracy of the emission inventory. It is assumed that derived diurnal factors for gas will be nearly the same for oil and coal, and that steam factors will reflect patterns of commercial space-heating with any fuel.

C. Model Availability

A computerized treatment for calculation of hourly emission estimates is not referenced in the paper.

IV FEDERAL HIGHWAY ADMINISTRATION

APRACMØD, Modification of APRAC-1A. P. W. Blow, FHWA.

A. Author's Abstract

None given.

B. Summary

APRACMØD is a modified version of the APRAC-1A urban diffusion model reported on in A Practical, Multipurpose Urban Diffusion Model for Carbon Monoxide. The purpose of the model is to estimate carbon monoxide concentrations at arbitrary points in an urban region resulting from projected vehicular travel.

The APRAC-1A urban diffusion model was modified to accept a standard FHWA Urban Transportation Planning Battery BUILDHR data set with carbon monoxide emission words added on each link record as input rather than the link card inputs for APRAC-1A. The modification further allows more links to be processed than the original program.

The program is composed of 17 separate decks and is written in FORTRAN.

EMISSION MODELS CHECKLIST

Input Data Requirements

	Within Program	User Supplies	From AP-42	Proxies/Comments
Vehicle Emission Factors				
-By model year	x	x		Average CO of vehicle mix for year of study interest
-By size class	x	x		
-By power plant	x	x		
-Deterioration factor	x	x		
Vehicle Operating Modes				
-Hot/cold start		NP		
-Route average		NP		
-Link average		x		Speed and Distance
-Mode-by-mode		NP	NP	
Traffic Features				
-Vehicle mix		NP		
-Engine operating time		NP	NP	
-Vehicle miles traveled		x	NP	
-Fuel consumed		NP	NP	
Spatial Distribution				
-Links		NP	NP	
-Grinds		x	NP	
-Area		x	NP	

NP = No provision

Output Available

Pollutants	
-CO	Yes
-HC	No
-NO_x	No
-Particulates	No

Availability of Program Documentation

	Yes	No
Included in report	x	
Referenced in report	x	
Language	FORTRAN	
Equipment	IBM 360	

Validation/calibration: Based on APRAC-1A

Time resolution: 1 hour

Spatial resolution: Radial segments-22.5° out to 16 km from receptor point

V FREE UNIVERSITY OF BERLIN

Numerical Simulation of Temporal and Spatial Distributions of Urban Air Pollution Concentration. H. D. Fortak, Proc. of Symposium on Multiple-Source Urban Diffusion Models, Chapel Hill, N.C., APCO Pub. No. AP-86, 1970.

A. Author's Abstract

A multiple-source diffusion model for the simulation and prediction of long-term (climatological) ground-level sulfur dioxide concentrations in urban areas is described. The computer input consists of data from an emission source inventory together with statistics on relevant diffusion parameters.

Because of the capacity of available computers, only a limited number of the largest emission sources (approximately 150) can be treated individually. Smaller industrial emission sources are treated as residential sources. These are represented by a large number of stacks (about 150) of the same dimensions, distributed over areas of 1 square kilometer, for which the mean area emissions have been estimated.

The meteorological input consists of data on wind direction, windspeed, and Pasquill-Turner stability classes. These parameters are assumed to be spatially homogeneous throughout the metropolitan area. Low-level emissions (residential) are correlated with low-level windspeeds and Pasquill-Gifford diffusion parameters, whereas high-level emissions (industrial) are correlated with extrapolated windspeeds and Brookhaven diffusion parameters. The program also uses corresponding statistics for urban boundary layer depths and values for parameters affecting absorption at the earth's surface.

The diffusion model used is basically Gaussian. It is modified, however, such that turbulent diffusion is restricted exclusively to the

depth of the urban boundary layer. This is true for all sources having effective emission heights less than the height of the upper limit of the boundary layer. The rate of decay of sulfur dioxide is taken into account, as well as the experimentally determined absorption at the earth's surface.

The model calculates fields of steady-state ground-level concentrations that correspond to a given spatial distribution of emission sources and to any possible combination of relevant meteorological diffusion parameters. Knowledge of frequency distributions of these meteorological diffusion parameters permits the derivation of frequency distributions of ground-level concentrations for any location within or outside of the metropolitan area. The computerized experiments simulate frequency distributions of ground-level concentrations for a great number of regularly arranged grid points (up to 2500 with a mesh size of 500 by 500 meters) and for a variety of time periods (months, heating period, seasons, year, etc.). The frequency distributions are characterized by a limited number of parameters (mean, percentiles, etc.). Each parameter is plotted as a system of isograms on a map of the metropolitan area.

Experiments to validate the model were conducted during the heating period in 1967-68 at four continuously monitoring stations that had been installed at special locations within the limits of the metropolitan area of Bremen. During the sampling period, the assumption of a sufficiently homogeneous wind field was validated by wind measurements at the same locations. The calculated frequency distributions of half-hourly mean values of concentrations generally agreed fairly well with those derived from observed values. Comparison, however, shows that the model does not simulate ground-level concentration fields in the vicinity of industrialized areas very well, because uncontrollable low-level emissions from industrial plants could not be taken into account in the diffusion model.

B. Summary

Sources in the city of Bremen, Germany, are classified in three groups. First are individual stacks with emission rates greater than one kilogram of SO_2 per hour, which are treated as point sources. Records for these sources contain information as to output by volume, maximum emissions, and mean winter and summer emissions. Whenever possible, daily emission variation data and emissions for holidays were obtained.

The second source category includes individual stacks from small industries that contribute less than 0.02% each to the total emission rate. Since these sources contribute such a small amount to the total emissions, they are treated in the same manner as emissions from space heating.

Emissions from space heating are apportioned as area sources in a 500 × 500-meter grid. From the sulfur content of the fuels, the total fuel consumption and the total number of dwelling units, a mean emission rate of 8 g SO_2/hr per dwelling unit is obtained. This rate assumed the daily mean temperature remains constant throughout the heating period. To make emissions from space heating a function of time, a relationship between daily mean temperature and daily emissions is used in some cases. Multiplying 8 g/hr (or the corresponding temperature corrected value) by the number of dwelling units in each area gives the mean emission rate for that area. This is then divided by the number of individual stacks representing the area source.

C. Model Availability

A computer code for the emission inventory methodology is not presented.

VI GENERAL ELECTRIC COMPANY

Study of Air Pollution Aspects of Various Roadway Configurations; APTD-1146; New York City Dept. of Air Resources, EPA, FHWA, New York Division Office; Prepared by General Electric Company, 3198 Chestnut Street, Philadelphia, Pa., 1971.

A. Author's Abstract

This experimental study was undertaken to (1) ascertain the current air quality in the immediate vicinity of various urban roadway configurations; (2) determine how the selected urban roadway configurations aid or hinder the diffusion of the pollutants emitted by urban traffic; and (3) develop mathematical relationships between traffic, traffic speed, pollutant concentration, meteorological parameters and roadway configuration. It is possible to assess the impact of the 1970 Clean Air Act by future monitoring programs which determine the extent to which the clean air goals are achieved. It is possible to identify those areas in and around a given configuration that do not meet the National Air Quality Standards under certain meteorological and traffic conditions. It is possible for urban and transportation planners to compute in advance the pollution anticipated for a proposed roadway design in order to insure that dwellings adjacent to the proposed design will not be exposed to pollutant concentrations in excess of the National Air Quality Standards.

B. Summary

One section of the report presents nomographs which provide highway designers with gross estimates of the CO concentration to be expected for various roadway configurations. Figure A presents representative relationships of CO concentration versus traffic flow rate for one of

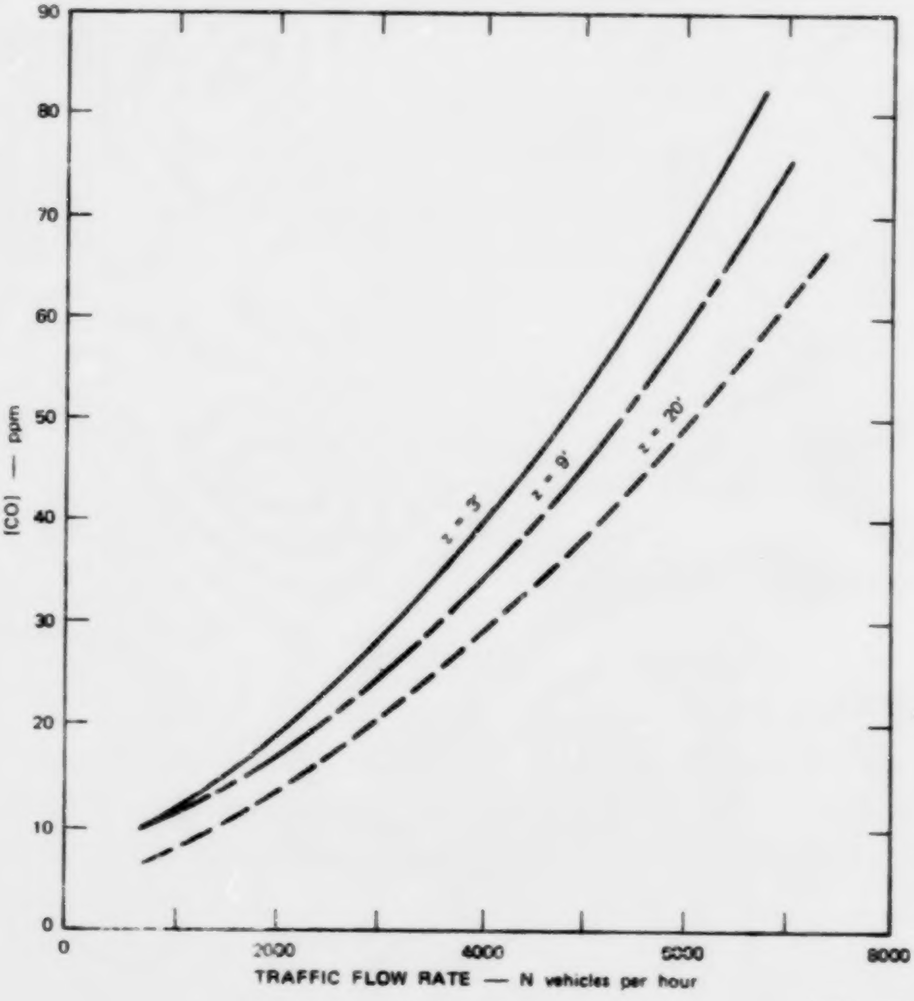


FIGURE B-3 PROFILE OF CARBON MONOXIDE VERSUS TRAFFIC FLOW RATE AT FDR DRIVE the ten sites monitored during this study. The CO values shown in the curves are those of the vertical plane of probes reflecting the maximum values. The traffic values shown are those of the total traffic involved.

Regression and correlation analyses were performed to determine whether the relationship between environmental variables and carbon monoxide and hydrocarbon concentrations could be predicted mathematically.

The resultant simple correlation coefficients and multiple correlation coefficient, R, show large variations. It must be concluded, therefore, that the postulated regression equation does not adequately describe the effects of the wind parameters on the carbon monoxide and hydrocarbon concentrations.

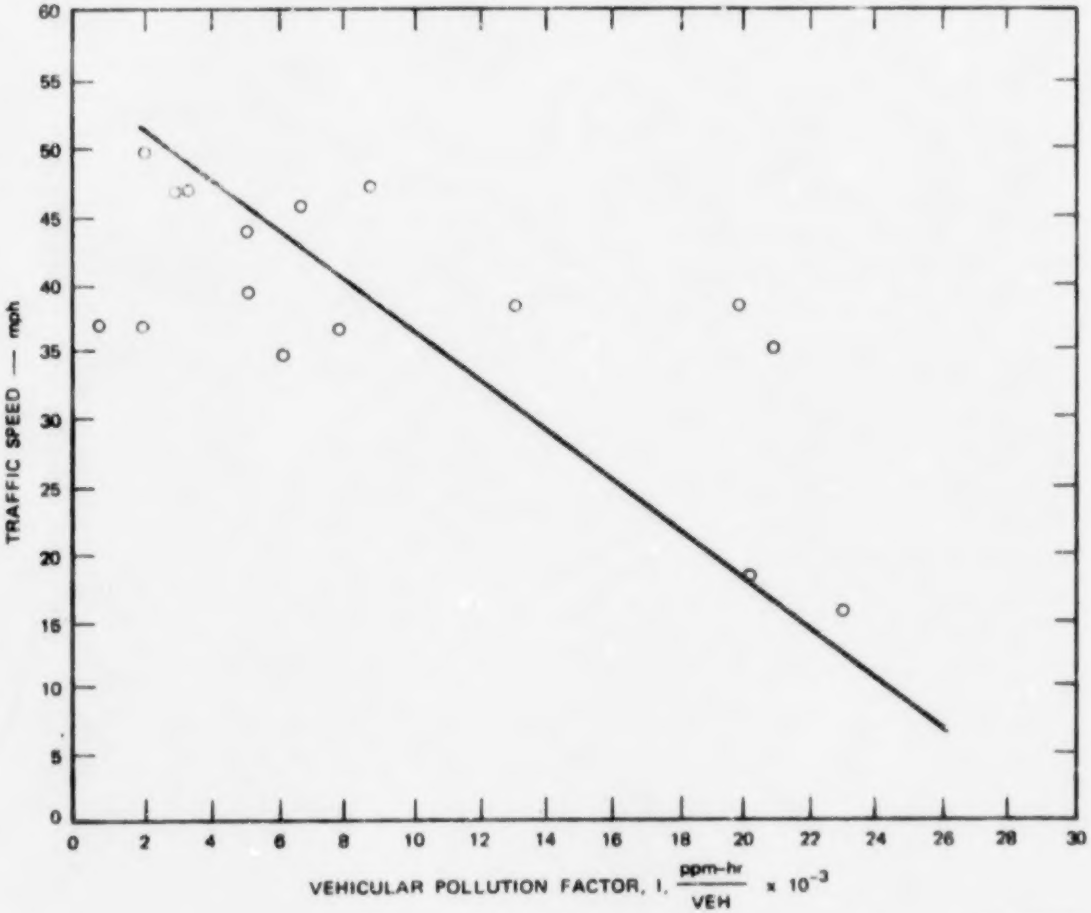
It is assumed that any given roadway can be divided into independent line sources and each probe located at the roadway measures the concentration from its immediate line source plus the concentration emanating from the other (x-1) line sources. Furthermore, it is assumed that the concentration decreases exponentially with distance from each probe location.

The model was further generalized by defining the vehicular pollution factor, ϕ , by dividing the unperturbed concentration, CO_2, by the traffic flow rate in the immediate vicinity of the probe location.

The vehicular pollution factor, ϕ ,

$$\phi = \frac{CO_x}{\dot{N}} \qquad (1)$$

For eight of the configurations evaluated, it was found that ϕ shows a strong linear relation with traffic speed (correlation of 0.81) as shown by Figure B. The viaduct site exhibited pronounced meteorological effects which resulted in the two lower points to the extreme left in the figure. The low velocity points in the lower right hand is data collected



SA-2579-28

FIGURE B-4 RELATIONSHIP BETWEEN VEHICULAR POLLUTION FACTORS TAKEN AT EXHAUST PLANE TRAFFIC SPEED in a city street. Data from the tunnel sites was not included in Figure B.

The linear relation between ϕ and traffic speed was found to be:

$$\phi_i = [-0.51 (T_i) + 26.9] = 10^{-3} \qquad (2)$$

for T: 15 mph $\leq T <$ 49 mph

ϕ_i = Apparent emission factor $\frac{\text{(PPM-Hr)}}{\text{veh}}$

T_i = Average Traffic Speed in lane i

It is seen from Equation (2) that traffic speed is the predominant factor and that the ranking of the sites must be based upon traffic speed, as well as site configuration. Stated in other terms, the line source strength decreases with increasing automobile speed due to the measure in vehicular induced turbulence and engine efficiency.

EMISSION MODELS CHECKLIST

Input Data Requirements

	Within Program	User Supplies	From AP-42	Proxies/Comments
Vehicle Emission Factors				
-By model year		NP		Experimentally measured at roadside for CO
-By size class	x	NP		
-By power plant		NP		
-Deterioration factor		NP		
Vehicle Operating Modes				
-Hot/cold start		NP		
-Route average		NP		
-Link average		NP		Average speed at point of measurement
-Mode-by-mode		NP	NP	
Traffic Features				
-Vehicle mix		NP		Hourly traffic count at point of measurement.
-Engine operating time		NP	NP	
-Vehicle miles traveled		NP	NP	
-Fuel consumed		NP	NP	
Spatial Distribution				
-Links			NP	
-Grinds			NP	
-Area		x	NP	Determined for area bounded by roadway configuration

---

NP = No provision

Output Available

Pollutants		
-CO	Yes	
-HC	No	(Could not obtain statistically "good" results)
-NO_x	No	
-Particulates	No	

Availability of Program Documentation

	Yes	No
Included in report		x
Referenced in report		x
Language	NP	
Equipment	NP	

Validation/calibration: Calibrated/validated for 10 different roadway configurations in NY Metropolitan area

Time resolution: 1 hour

Spatial resolution: Area occupied by roadway configuration

VII GENERAL RESEARCH CORPORATION

Evaluation of a Diffusion Model for Photochemical Smog Simulation. A. Q. Eschenroeder, J. R. Martinez, and R. A. Nordsieck, Final Report, General Research Corporation, prepared for Environmental Protection Agency, Contract No. 68-02-0336, October, 1972.

A. Author's Abstract

Extensive improvements have characterized this evaluation of the GRC Photochemical/Diffusion model. Despite the limitations of smog chamber experimental data, they have served an essential purpose toward updating the kinetics portion of the model. Consistency of rates and reactivities is now achievable using recently measured coefficients for a wide variety of systems. Model methodology revisions have enhanced the realism of the advective and diffusive descriptions. Previous assumptions regarding transverse (cross-streamline) horizontal diffusion have been confirmed by an exhaustive series of parametric tests. Photochemical/diffusion validations were successful for trajectories occurring during four days of the 1969 smog season in Los Angeles. Our measure of success is concentration-history fidelity with a minimum of adjustments of diffusion parameters. (Chemical coefficients were scaled from the smog chamber studies and held fixed for the simulations carried out to date.) Future directions for air pollution model development are discussed in detail in an appendix as information supporting the experimental recommendations.

B. Summary

General Research Corporation's diffusion model uses hourly emissions of carbon monoxide, ozone, hydrocarbons, nitrogen dioxide and nitric oxide from both fixed and moving sources on a 2-mile interval grid to predict pollutant concentrations. The emissions inventory used is that compiled by Systems Applications, Inc., (see Review No. XXII).

VIII GEOMET

Validation and Sensitivity Analysis of the Gaussian Plume Multiple-Source Urban Diffusion Model. R. C. Koch and S. D. Thayer, Geomet, Inc., Final Report, Contract No. CPA 70-94, prepared for Environmental Protection Agency, November, 1971.

A. Author's Abstract

This report, submitted by GEOMET to the National Environmental Research Center, presents the analysis and results of a program of validation and sensitivity analysis of the steady-state Gaussian plume-type of urban diffusion model.

The report develops a careful definition of the fundamental short-term steady-state model and its various modes of implementation, in terms of emission and environmental input parameters, and of calculational modes. A set of computer programs developed especially for validation and sensitivity study purposes is described.

The validation study consists of a variety of comparisons of short-term and long-term concentration predictions from the model, with comparable measured SO_2 concentrations covering three months of 2-hour values at ten locations in St. Louis, and one month of 1-hour values at eight locations in Chicago. The predictions use hourly estimates of meteorological and emission parameters. The atmospheric stability is estimated from hourly weather observations from an adjacent airport using the McElroy-Pooler diffusion parameters based on Turner's definitions of stability categories. The mixing layer ceiling is estimated from radiosonde observations taken twice daily from remote locations (100 to 200 miles away). The wind speed and direction are

hourly averages of several continuous records. The emission rates of the largest sources are identified and located individually. For other sources a mean emission rate per unit area is estimated for a square gridwork of points with a one-mile spacing between adjacent points. Each emission rate is related to hourly estimates of space heating and other operating requirements. No "calibration" or other adjustment of the inputs or output concentrations is employed anywhere in the analysis.

Individual short-term model results (1- to 2-hour periods) show large deviations from the observed concentrations, but the frequency distributions of calculated short-term concentrations over a month or a season compare quite well with the comparable frequency distributions of observed concentrations. No single factor could be found which accounts for a significant fraction of the individual deviations. Predicted long-term concentrations show consistently good agreement with observations, as contrasted with the significant overestimation usually found in other model implementations.

A technique is proposed for calculating the long-term estimates which obviates the need to calculate every short-term concentration in the period. A sampling process is used in which a statistically selected set of as few as five to ten percent of the short-term periods is employed, and the representativeness of the distribution is maintained.

In the sensitivity analysis, the insensitivity of the model concentrations to the parameters of wind speed profile parameter value, and the distribution of area source emission heights, is demonstrated. Quantitative description is given of the sensitivity of the model to the following parameters: changes in spatial variability in emissions, vertical diffusion parameter, pollutant half-life, wind speed, mixing ceiling, wind direction, and downwind variation in emission rates.

Finally, recommendations are made on implementation and use of the model described herein, and for further study in special problem areas highlighted by the study.

B. Summary

The GEOMET multiple-source diffusion model designates individual sources with emission rates significantly higher than the average rate as point sources, e.g., power plants, large industrial plants, and large commercial and municipal emitters. For the remaining emitters (area sources such as residential homes, high-rise apartments, and various smaller commercial and industrial establishments), it is assumed that an average emission rate is representative of a small region. Hourly estimates of SO_2 point and area source emission rates are required. Two methods of parameterizing temporal and spatial variations of these rates have been used in this study, one for the St. Louis emissions data and one for the Chicago data.

1. Treatment of St. Louis Emission Data

The following algorithms for estimating SO_2 emissions as a function of time of day, day of week, location, and temperature were adapted from methods developed by D. B. Turner.*

a. Area Sources

Area source emissions were divided into 5000 × 5000-foot grid squares, and included data from residential, commercial, river vessel, automobile, railroad, backyard burning, and industrial sources. Turner suggests the following algorithm for area sources:

---

* Personal communication to GEOMET, Inc.

$$Q(t) = Q_r + q_r D_r(t) + Q_c F_c(t) + q_c D_c(t) + Q_v + Q_a F_a(t) + Q_w + Q_b$$
$$+ q_x D_c(t) + Q_p F_d(t) F_h(t)$$

$$D_r(t) = 65 - T(t) - \Delta_r(t)$$

$$D_c(t) = 65 - T(t) - \Delta_c(t)$$

where $Q(t)$ = SO_2 emission rate

Q_r = base residential SO_2 emission rate

q_r = residential heating SO_2 emission rate per degree

$T(t)$ = ambient air temperature

$\Delta_r(t)$ = residential temperature correction factor

$\Delta_c(t)$ = commercial temperature correction factor

Q_c = base commercial SO_2 emission rate

$F_c(t)$ = commercial diurnal variation factor

q_c = commercial heating SO_2 emission rate per degree

Q_v = river vessel SO_2 emission rate

Q_a = base automotive SO_2 emission rate

$F_a(t)$ = automotive diurnal variation factor

Q_w = railroad SO_2 emission rate

Q_b = backyard burning SO_2 emission rate

q_x = industrial heating SO_2 emission rate per degree

Q_p = base industrial process emission rate

$F_d(t)$ = industrial day of week variation factor

$F_h(t)$ = industrial diurnal variation factor

Introducing subscript notation, let i,j appear on parameters that vary from one area source to another, let k denote fuel type, a denote annual or national average, and ℓ refer to the hourly period. Then

$$(q_r)_{ij} = \frac{H_a R_{ij}}{D_a R_a} \sum_{k=1}^{K} \frac{S_k (N_k)_{ij}}{E_k H_k}$$

where H_a = average annual U.S. household space heating energy requirement

D_a = average annual U.S. degree days

R_a = average number of rooms per U.S. household

R_{ij} = average number of rooms per dwelling unit in grid square (i, j)

S_k = SO_2 emitted per unit fuel k

E_k = heating efficiency of fuel k

H_k = heat content of fuel k

$(N_k)_{ij}$ = number of residential dwelling units using fuel k in grid square (i,j)

$$(Q_r)_{ij} = \frac{F_s}{1-F_s} (q_r)_{ij} \overline{D_w}$$

K = number of fuels

where F_s = summer day fuel consumption as fraction of average winter day

$\overline{D_w}$ = average winter degree day

$$(Q_c)_{ij} = \frac{1}{\Delta t_s} \sum_{k=1}^{K} S_k \sum_{\ell=1}^{C_{ij}} (F_s)_{k\ell} W_{k\ell}$$

where Δt_s = duration of season

C_{ij} = number of commercial sources in grid square (i,j)

$W_{k\ell}$ = annual quantity of fuel k used by ℓth source

$\left(F_s\right)_{k\ell}$ = fraction of annual quantity of fuel k used by ℓth source in summer season

S_k = SO_2 emitted per unit of fuel k

$$\left(q_c\right)_{ij} = \frac{1}{D_w}\left\{ \frac{1}{\Delta t_s}\left[\sum_{k=1}^{K} S_k \sum_{\ell=1}^{C_{ij}} \left(F_w\right)_{k\ell} W_{k\ell}\right] - \left(Q_c\right)_{ij} \right\}$$

where D_w = winter season degree days

$\left(F_w\right)_{k\ell}$ = fraction of annual quantity of fuel k used by ℓth source in winter season

$$\left(q_x\right)_{ij} = \frac{1}{D_w} \sum_{k=1}^{K} S_k \sum_{\ell=1}^{I_{ij}} \left(F_w\right)_{k\ell} W_{k\ell}$$

where I_{ij} = number of industrial sources in grid square (i,j)

Substituting, the original algorithm becomes

$$Q_{ij}(t) = \left[\frac{F_s \overline{D_w}}{1-F_s} + 65-T(t)\right] - \Delta_r(t)\ \frac{H_a R_{ij}}{D_a R_a}\left[\sum_{k=1}^{K} \frac{S_k \left(N_k\right)_{ij}}{E_k H_k}\right]$$

$$+ \left[\frac{F_c(t)}{\Delta t_s} - \frac{65-T(t) - \Delta_c(t)}{D_w}\right]\left[\sum_{k=1}^{K} S_k \sum_{\ell=1}^{C_{ij}} \left(F_s\right)_{k\ell} W_{k\ell}\right]$$

$$+ \frac{65-T(t) - \Delta_c(t)}{D_w}\left[\sum_{k=1}^{K} S_k \sum_{\ell=1}^{C_{ij}} \left(F_w\right)_{k\ell} W_{k\ell}\right]$$

$$+ Q_v + Q_a F_a(t) + Q_w$$

$$+ Q_b + \frac{65-T(t) - \Delta_c(t)}{D_w}\left[\sum_{k=1}^{K} S_k \sum_{\ell=1}^{I_{ij}} \left(F_w\right)_{k\ell} W_{k\ell}\right]$$

$$+ F_d(t)F_h(t)\sum_{\ell=1}^{I_{ij}} \left(Q_p\right)_\ell$$

Effective emission heights for area sources are determined primarily on the basis of prevalent building heights in the area.

b. Point Sources

Industrial Sources. Sulfur dioxide emissions from industrial sources are comprised of emissions from process and space heating fuel consumption. Process fuel emissions are estimated by the product of the peak process emission rate and factors related to the temporal variation of emissions. Space heating emissions are determined in terms of degree day response. The SO_2 emission rate, $Q(t)$, is expressed by

$$Q(t) = Q_pF_d(t)F_h(t) + q_xD_c(t)$$

where Q_p = peak process SO_2 emission rate

$F_d(t)$ = fraction of peak for day of week

$F_h(t)$ = fraction of peak for hour of day

q_x = heating fuel SO_2 emission rate per degree

$D_c(t) = 65 - [T(t) + \Delta_c(t)]$

$T(t)$ = ambient air temperature

$\Delta_c(t)$ = commercial temperature correction factor

The quantities Q_p, $F_d(t)$ and $F_h(t)$ are obtained from questionnaires containing plant operation statistics. According to season, q_x is

$$q_x = \frac{1}{D_a} \sum_{j=1}^{n} W_j S_j$$

or

$$q_x = \frac{1}{D_w} \sum_{j=1}^{n} \left(F_w\right)_j W_j S_j$$

where W_j = annual quantity of fuel j used

S_j = SO_2 emitted per unit fuel j

D_a = annual number of degree days

D_w = winter season degree days

$\left(F_w\right)_j$ = fraction of annual quantity of fuel j used in winter season

The SO_2 emission rate equation then becomes

$$Q(t) = Q_p F_d(t) F_h(t) + [65 - T(t) - \Delta_c(t)] \frac{1}{D_a} \sum_{j=1}^{n} W_j S_j \quad .$$

In addition to emission rate parameters, data inputs include location coordinates of the source, physical stack height and the plume rise, wind-speed product.

Power Plant Sources. According to the available data, one of two methods of estimating power plant emission is used.

For some plants hourly power outputs were available. The information included graphs of fuel weight flow rate, stack temperature, and stack exit gas volume flow rate as functions of power output. A linear relationship was found between fuel flow rates and power output:

$$F = A_1 + A_2 L$$

where F = fuel weight flow rate

L = power output

A_1, A_2 = empirical parameters

Emission rates are

$$Q = FE \frac{S}{100}$$

where Q = SO_2 emission rate

F = fuel flow rate

E = SO_2 emission factor

S = percent sulfur content of fuel

Stack temperature and volume flow rate are also linearly related to output, but it was found necessary to divide the range of power outputs from zero to a peak value into three equal parts and to use a linear approximation over each part or class of the range. This gives

$$T_s = T_\ell + \frac{\left(L - L_\ell\right)}{L_p/3} \left(T_u - T_\ell\right)$$

where T_s = stack temperature

L = power output

L_ℓ = lower limit of power output class

L_p = peak power output

T_ℓ = stack temperature for power load of L_ℓ

T_u = stack temperature for power load of $L_\ell + L_p$

and

$$V_s = V_\ell + \frac{L-L_\ell}{L_p/3}\left(V_u - V_\ell\right)$$

where V_s = stack gas volume flow rate

V_ℓ = stack gas volume flow rate for power load of L_ℓ

V_u = stack gas volume flow rate for power load of $L_\ell + 1/3\ L_p$

For another plant, estimates were made for each two-hour period of the day of average emission rates, wind speed and plume rise product. These estimates were derived by government personnel based on discussions with the plant operator, and are assumed representative of all days in the data period.

2. Treatment of Chicago Emission Data

The algorithms employed by GEOMET to obtain hourly SO_2 emission rates from the Chicago emission data were those developed by Argonne National Laboratory and described previously in Section II of this appendix. The area source grid consists of one mile squares. Additions to the algorithms include Turner's temperature correction factor in the residential and commercial area source treatments and the following equation for describing heat emission rates for the three classes of additional point sources:

$$H_e = 0.15\,\frac{240\ Q}{\frac{S}{100}\ 3680\ N}$$

where H_e = heat emission rate

Q = SO_2 emission rate

S = percent sulfur content of fuel

N = number of stacks

3. Model Sensitivity

Sensitivity to the vertical distribution of area source emissions was investigated. It was concluded, for the cases tested, that in general the differences resulting from the use of various vertical distributions were negligible.

To study model sensitivity to diurnal variation in emission rates, the factors(represented by algorithms) which affect emission rate estimations were analyzed. The inputs to the algorithms are temperature, electric power load at generating stations, and hour of the day, but errors associated with the measurement of these inputs are small. Therefore, the assumptions made in formulation of these algorithms were investigated.

In the emissions model, annual emission rates act as scaling factors for diurnal variations; an error in one of these estimates creates systematic error in model predictions. However, the authors feel that if concentrations are considered at a number of widely dispersed locations, the errors tend to cancel each other.

Sulfur dioxide emissions are characterized as arising from three classes of operations: (1) electric power generation, (2) industrial processing and (3) space heating. Hourly power plant emissions are estimated by means of linear relationships with hourly electric power load of individual generating units. Error in this regard is small, but uncertainty would be increased for proposed power plants where hourly loads would need to be predicted.

Diurnal emissions from industrial processing are allocated on the basis of utilization factors concerning day of the week, hour of the day, etc. Variations between actual and estimated emissions may be considerable, since industrial operations must respond to fluctuations in demand and breakdowns in equipment. The authors state that errors in emission rate estimated in the immediate vicinity of individual sources result, but a random distribution of these over an urban area tend to balance.

Algorithms for emissions from space heating operations contain correction factors such as Turner's temperature correction factor and Argonne's "janitor function." It was felt that random errors associated with individual sources of these types are probably small, and a more serious type of error is associated with the assumputions in the algorithms of no time lag between outside temperature change and fuel consumption. This type of error is critical to short-term model sensitivity, sometimes resulting in an emission error of a factor of 2; it is not important in calculating long-term concentrations.

Systematic errors due to unseasonable temperatures can result when thermostats are controlled only partially by temperature, since the algorithm will immediately respond to the temperature change. In these cases, the emission rate error will persist for the duration of the unseasonable weather. The resulting concentration error will be minimal over the long-term, but short-term concentration error will be directly proportional to the emission error. A careful study of the magnitude and duration of heating emissions is required to determine the nature of heating system response to rapid and extreme temperature fluctuations.

C. Model Availability

Computer program listings of the emissions treatments for both Chicago and St. Louis data appear in the GEOMET report.

IX IBM

The IBM Air Quality Diffusion Model with an Application to New York City. L. J. Shieh, P. K. Halpern, B. A. Clemens, H. H. Wang, and F. F. Abraham, IBM Corp., Palo Alto Scientific Center, Report No. G320-3290, June, 1971.

A. Author's Abstract

An experimental multisource air pollution diffusion model based on the Gaussian plume formulation is described. The model is capable of incorporating point and area sources, time and space dependence of source strengths, and time and space dependence of meteorological variables. Numerical experiments sumulating the SO_2 concentration distribution for New York City are presented for January 11, 1971. The numerical results agree favorable with experimental measurements.

B. Summary

The IBM diffusion model requires 2-hourly SO_2 emissions data in order to predict the average ground level concentrations for a 2-hour interval. The emissions treatment recognizes individual point sources, which include power generation, municipal incinerators, manufacturing plants, industrial combustion, chemical and oil refinery and mineral smelting, large hospitals, etc; and area sources, which account for commercial and domestic space and hot water heating.

1. Treatment of Area Sources

The grid square size for area sources is variable, allowing for specification of different grids for urban, sub-urban, and rural areas. These specifications are based on receptor locations relative to the sources and the distribution of source strengths. Computations were made using a 1.0 × 1.0-mile square grid in the urban area, 2.0 × 2.0 in the sub-urban area, and 4.0 × 4.0 in the rural area. Necessary inputs include the number of different area source sizes used and the number of area source grids in each area source size; the model groups source grids (for any grid size) in a rectangular region, thus also requiring as input the number of rectangular regions for the entire source grid; and, for each region, the x,y coordinates denoting the limits of the region and the size of the source grid for that region.

A source emission height for each area source size must be input to the model, and it is taken as the average building height within the area source grid.

Total annual SO_2 emissions are first broken down into daily, then 2-hourly emissions. One method used to generate daily patterns was to relate daily emissions to the average daily temperature, where

$$Q_{daily} = \gamma_1 \frac{Q_{annual}}{365} + \gamma_2 \frac{Q_{annual}}{TDD} (DD)$$

and Q_{daily} = daily total SO_2 output

Q_{annual} = annual total SO_2 output

DD = degree days = 65 - daily mean temperature in °F if the latter is 65°F or less; otherwise, it is zero

TDD = annual total degree days

γ_1 = fraction of sources due to hot water heating

γ_2 = fraction of sources due to space heating

and $\gamma_1 + \gamma_2 = 1$

An alternate approach divides the calendar year into three seasons and allocates fractions of the annual source emissions to each season. Let α_1, α_2 and α_3 represent these fractions. The seasonal emissions may be written as

$$Q_{\text{season 1}} = \alpha_1 \, Q_{\text{annual}}$$

where $\alpha_1 + \alpha_2 + \alpha_3 = 1$

Daily emissions are found by dividing by the number of days in the season in question. Estimates of daily emissions using this method are not as precise as those calculated by the former method. To reduce daily SO_2 output to 2-hourly source emissions, statistically derived coefficients representing diurnal variations of emissions as a function of ambient temperature are introduced. It is assumed that for each 10°F interval of daily mean temperature a typical diurnal emission pattern exists, from which these coefficients can be derived. Two-hour source emissions are calculated with the expression:

$$\sum_{i=1}^{12} Q\left(2 \text{ hour}_i\right) = \sum_{i=1}^{12} \beta_i \, Q_{\text{daily}}$$

where β_i (i=1, 12) equals the fraction of daily output at a particular 2-hour interval. Values of β_i are given in the table.

Small point sources are included with the area source emissions if certain criteria are satisfied: (1) the total annual emissions are less than one-tenth of the total annual emissions of the associated area source; (2) the stack height of the point source is within 20 m of the associated area source emission height; and (3) the point source has no appreciable plume rise. All other point sources are considered individually.

2. Treatment of Point Sources

The model requires bi-hourly emissions data from point sources, and if measured data are not available, the following simulation technique

β_1[*]

Temperature Range	Local Time											
	00-0200	02-0400	04-0600	06-0800	08-1000	10-1200	12-1400	14-1600	16-1800	18-2000	20-2200	22-0000
≥ 60°F	5.0	3.0	7.0	10.0	10.0	10.0	9.0	9.0	10.0	10.0	10.0	7.0
50-59°	3.0	3.0	11.0	14.0	12.0	9.0	7.0	7.0	9.0	10.0	9.0	6.0
40-49°	3.0	3.0	9.0	10.0	11.0	10.0	10.0	9.0	10.0	10.0	10.0	5.0
30-39°	3.0	3.0	9.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	9.0	6.0
≤ 29°	5.0	6.0	9.0	10.0	9.0	9.0	9.0	8.0	9.0	10.0	9.0	7.0

---

[*] These coefficients were determined using limited data obtained in New York City during 1966. IBM Corporation stresses that these data should be used with extreme care when attempting application to other cities during other years, and state that they are not responsible for their accuracy.

(i.e., emission model) is suggested by the authors. Point sources are classified according to industry, and operational modes for each industry are established. Patterns for daily output will vary according to mode of operation; that is, operation on weekdays versus weekends, seasonal trends, shift factors, etc. Several patterns for a particular industry are distinquished, and diurnal emissions are obtained through the application of the various factors derived from the patterns appropriate to the mode of operation under consideration.

C. Model Availability

The computer program for the IBM model is considered experimental and is not available outside IBM.

X IBM

Source Emissions and the Vertically Integrated Mass Flux of Sulfur Dioxide Across the New York City Area.
P. Halpern, C. Simon, and L. Randall, Journal of Applied Meteorology, 1971.

A. Author's Abstract

Sulfur dioxide concentrations (in ambient air), obtained from helicopter soundings and traverses, together with wind data from pibals, were used in a kinematic box model to determine hourly average three-dimensional fluxes of SO_2 for the New York City area. Continuous dry-bulb temperature and pressure height records were obtained concurrently and utilized in the analysis and interpretation of the flux data.

The SO_2 fluxes were compared to degree-day-dependent emissions from residential, industrial and utility sources. Results indicate that the vertical structure of the fluxes is related to diurnal variations of the temperature lapse rates. Furthermore, the emission rates determined from the measurement of flux in 13 tests agree with those derived from the New York City sulfur dioxide emission inventory within limits which have been considered acceptable for use in air pollution modeling.

B. Summary

1. Treatment of Emissions

The emissions treatment described by Halpern et al., considers hourly SO_2 emissions from residential, utility, and industrial sources. Hourly values of power plant emissions were obtained from the utility companies. Hourly manufacturing and industrial emissions are estimated by uniformly distributing annual emissions data over an 8-hour day, 5-day week, and 50-week year. Daily residential emissions are obtained in the manner described in the IBM model summary previously given. Diurnal variations in residential rates are estimated using data on duration of hourly operation times for apartment house boilers using fuel oil. Total boiler operating time for each day is correlated with degree day values:

$$t = 17.2TT + 192.0$$

where t equals the total operation time of the boiler in minutes and TT represents the degree days. Since space-heating boilers receive fuel oil at a constant rate when operating, knowledge of t and the fuel sulfur content is sufficient to describe the hourly SO_2 emission rate.

2. Model Validation

Sulfur dioxide fluxes are calculated from concentration measurements taken by a helicopter and using wind measurements obtained from pibal and radiosonde soundings. A kinematic box model based on conservation of mass is used to verify the hourly emission rates and to demonstrate a mass balance of SO_2.

For thirteen test cases, the vertically integrated SO_2 flux was greater than the flux estimated from the emissions inventory. The average value of the ratio of source emissions flux to the vertically integrated flux was 0.74 for tests during May and 0.83 for tests in November. The authors state that this indicates that the source emission estimates were more responsive to the degree-days dependence in the colder November tests than in the warmer May tests. The average value for the ratio for all tests was 0.78.

The mass balance of SO_2 has been verified by comparing calculated SO_2 flux to source emission data.

C. Model Availability

A computer program for the emission inventory methodology presented is not included in the paper.

XI METROPOLITAN WASHINGTON COUNCIL OF GOVERNMENTS

Estimating Auto Emissions of Alternative Transportation Systems; Office of the Assistant Secretary for Environment and Urban Systems, Washington, D. C. 20590; Prepared by S. D. Berweger and G. V. Wickstrom, Dept. of Transportation Planning, Metropolitan Washington Council of Governments, 1972.

A. Author's Abstract

This report discusses the development and application of a model which can estimate the relative magnitudes of carbon monoxide, hydrocarbons, and oxides of nitrogen automobile emissions for alternative regional transportation systems.

The computation of auto emissions is accomplished by means of a computer program which accepts travel and facility data, together with assumed emission rates, and calculates speed and vehicle-miles of travel by type of facility by sub-area; applies the rates (for peak and off-peak travel speeds and volumes) and calculates the amount of emission by sub-area. Emission rates are a function of the speed of travel and the age distribution of vehicles in the year under study. A portion of the program logic is based on a model developed by the Tri-State Transportation Commission for estimating highway facility requirements, modified for the purpose of calculating auto emissions.

These findings are based on the emission factors supplied by E.P.A. If these factors are revised as a result of further research, it is quite possible that some of the results obtained would change. Revisions to the emission factors can be readily accommodated by the model developed in this study.

B. Summary

The methodology makes use of vehicle trip forecasts, along with highway network information, to estimate future travel, the speeds at which this travel will occur, and the emission levels produced. The methodology does not require trip distribution and traffic assignment model procedures. It is aimed at providing a regional overview of the relative magnitude of the air pollution problem in an area. The methodology is not intended to provide air quality forecasts as no diffusion models have been used.

For each system, estimates of average daily and peak-hour emissions of carbon monoxide (CO), hydrocarbons (HC), and oxides of nitrogen (NO_x) were made and compared. Computer programs have been developed to do much of the work and are available.

The three-stage Auto Emissions Model developed in this study is shown in the figure. For each system tested, a trip generation sub-model is used to determine automobile vehicle trip origins, a travel description sub-model is utilized to convert those trips into travel characteristics and, finally, an emission sub-model is used to convert these travel parameters into estimates of pollutant emissions.

The emission sub-model utilizes average speeds, to determine the CO, HC, and NO_x emission rates, in pounds per vehicle mile, for each facility type. This rate is then multiplied by the VMT on each facility type to determine the total pollutants emitted for each of the sub-areas. This process is carried out for both peak-hour and daily conditions.

The emission factors used in this study were supplied by the E.P.A. CO and HC emissions per vehicle-mile of travel decrease with increasing speeds while emissions of nitrogen oxides are assumed to be constant for all speeds.

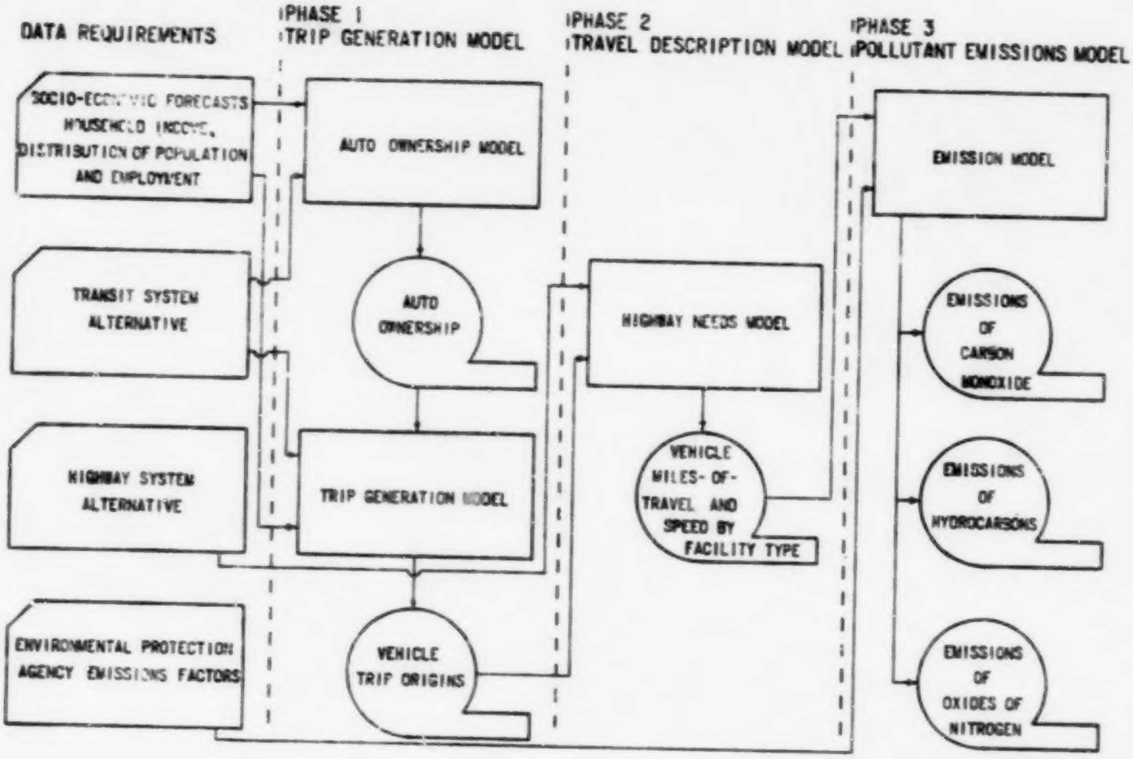

DATA REQUIREMENTS
PHASE 1
TRIP GENERATION MODEL
PHASE 2
TRAVEL DESCRIPTION MODEL
PHASE 3
POLLUTANT EMISSIONS MODEL
SOCIO-ECONOMIC FORECASTS HOUSEHOLD INCOME, DISTRIBUTION OF POPULATION AND EMPLOYMENT
TRANSIT SYSTEM ALTERNATIVE
HIGHWAY SYSTEM ALTERNATIVE
ENVIRONMENTAL PROTECTION AGENCY EMISSIONS FACTORS
AUTO OWNERSHIP MODEL
AUTO OWNERSHIP
TRIP GENERATION MODEL
VEHICLE TRIP ORIGINS
HIGHWAY NEEDS MODEL
VEHICLE MILES-OF-TRAVEL AND SPEED BY FACILITY TYPE
EMISSION MODEL
EMISSIONS OF CARBON MONOXIDE
EMISSIONS OF HYDROCARBONS
EMISSIONS OF OXIDES OF NITROGEN
SA-2579-29

FIGURE B-5 FLOW CHART OF AUTO EMISSIONS MODEL

There was concern over combining trip specific speed-emission factors with facility specific speeds. At the time the study was initiated, however, there were no data available to resolve this inconsistency.

The most important relationship used in the travel description sub-model is between vehicle-miles of travel (VMT) density, vehicle trip origin density, and expressway supply. In the Washington, D.C. area, the relationship was found to be the same as that found in the New York region, that is:

$$VMT = 64.3 \times VTO^{0.74} \times e^{(1.6 \times FE/FO)}.$$

where:

VMT = vehicle-miles of travel per square mile

VTO = vehicle trip origins per square mile

FE/FO = proportion of total roadway surface area made up by expressways

It was found that the expressway speed estimates calculated for the New York region were too high for use in the Washington area; therefore, the source deck was recompiled using a speed equation specifically calibrated for the Washington region.

To obtain an estimate of peak-hour speeds, the 24 hour VMT was factored to peak hour volumes per lane by facility type, using observed peak-to-daily and directional flow factors. The Technical Advisory Committee eventually decided that the EPA emission factors published in the EPA document, "Air Pollution Emission Factors"* were the best available for current use. These factors were modified somewhat by EPA to account for 1976 conditions and the fact that the age distribution of automobiles in the Metropolitan region was different (younger) than the national average.** This resulted in a slightly lower base emission rate for the region, but the proportional changes in rates for speed variations remained identical to that published.

Preliminary data from a current five-car study in California indicates that the impact of control devices might well be to flatten out the CO and HC curves, that is, emission rates may not decrease as rapidly for a given speed increase as they did under the old curves.

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* M. J. McGraw, and R. L. Duprey, "Compilation of Air Pollutant Emission Factors" (Preliminary Document), Environmental Protection Agency, Research Triange Park, N. C., April, 1971.

** "Motor Vehicle Emission Factors for Metropolitan Washington, D.C.," Environmental Protection Agency, Office of Air Programs Memo, November 4, 1971.

EMISSION MODELS CHECKLIST

Input Data Requirements

	Within Program	User Supplies	From AP-42	Proxies/Comments
Vehicle Emission Factors				
-By model year		x	x	
-By size class			NP	
-By power plant			NP	
-Deterioration factcr			NP	
Vehicle Operating Modes				
-Hot/cold start	NP			Average speeds for each mode based on total VMT by mode
-Route average	NP			
-Link average	NP			
-Mode-by-mode	NP		NP	
Traffic Features				
-Vehicle mix	NP			
-Engine operating time	NP		NP	
-Vehicle miles traveled	x		NP	
-Fuel consumed	NP		NP	
Spatial Distribution				
-Links			NP	
-Grinds			NP	
-Area		x	NP	

NP = No provision

Output Available

Pollutants	
-CO	Yes
-HC	Yes
-NO_x	Yes
-Particulates	No

Availability of Program Documentation

	Yes	No
Included in report	x	
Referenced in report	x	
Language	Basic FORTRAN IV	
Equipment	IBM 360/30	

Validation/calibration: Calibrated/validated on emissions for Metropolitan Washington, D.C.

Time resolution: Peak/off-peak

Spatial resolution: Area specified by zonal configuration

XII NATIONAL AIR POLLUTION CONTROL ADMINISTRATION

St. Louis SO_2 Dispersion Model Study--Basic Data.
D. B. Turner and N. G. Edmisten, Unpublished report,
November, 1968.

A. Author's Abstract

This report contains descriptions of basic data for a three month period used with a research study formulating a dispersion model for the St. Louis Metropolitan Area. This includes emission information for sources of sulfur dioxide as well as methods of estimating emissions for each 2-hours for the three-month period, hourly meteorological data from routine and special instrumentation, and 24-hour sulfur dioxide concentrations for 40 locations and 2-hour concentrations for 10 locations.

B. Summary

This unpublished report outlines methods of computing the number of dwelling units per grid square and the population per grid square, from basic census data.

1. Estimation of the Number of Dwelling Units per Grid Square

When the census tracts are larger than a grid square, the procedure is to first calculate the total number of grid squares per census tract by dividing the number of acres in the tract by the number of acres in a grid square. The number of inhabited grid squares in the tract is estimated, deleting rivers, lakes, parks, etc. Weights are then assigned individually to the squares to adjust their dwelling unit density to that of the total census tract. The number of each type of heating unit (coal, gas, or oil) is estimated for an average grid square from census data.

Finally, the number of each type of heating unit per average grid square is multiplied by the assigned weights, giving the number of each type of unit in the grid square in question.

When the census tract is smaller than a grid square, the fraction of the total census tract in each grid square of which it is a part is estimated, and weights are assigned to each portion of the tract to compensate for nonresidential areas. The total number of each type of unit in the census tract is multiplied, individually, by the fraction of area and by the assigned weight. These products are summed for each of the census tracts within the grid square, yielding the number of each type of unit in the square.

2. Estimation of the Population per Grid Square

When the census tract is larger than a grid square, the total number of grid squares per census tract is calculated, and the number of inhabited grid squares in the tract is estimated. Weights are individually assigned to the squares to adjust their population density to that of the total census tract. By dividing the population of the total census tract by the number of grid squares per tract, the number of people per grid square is found. Finally, multiplying the average grid square population by the assigned weight gives the population of the grid square in question.

If the census tract is smaller than a square, the fraction of the total census tract in each grid square of which it is a part is estimated, and a weight is assigned to each portion of the tract to compensate for nonresidential areas. The total population of the tract is multiplied, individually, by both the fraction of area and the assigned weight, and the sum of these products, for each census tract within the grid square, equals the population of the square.

C. Model Availability

A computer code for the methodology presented is not included in the report.

XIII NATIONAL AIR POLLUTION CONTROL ADMINISTRATION

Emission Factors. A. H. Rose, Jr., W. D. Krostek, National Air Pollution Control Administration, June, 1969.

A. Author's Abstract

A method has been developed for the prediction of gaseous pollutants emitted into the national environment from on-the-road gasoline-powered vehicles. The method involved two quantities, the emissions emitted per mile traveled, and the total mileage traveled. Vehicular emissions were characterized by engine type and load under actual operating conditions. Five vehicle types and two use classes were used to define characteristic vehicular emissions. Vehicle types were automobile (auto), light duty truck (LDT), and three weight classes of heavy duty trucks (HDT). The two use classes were urban and rural.

The method allows comparison among the possible degrees of control, methods of control, and implementation dates. The method could be utilized on a regional rather than national basis, and could include particulates as well as gaseous pollutants.

B. Summary

1. Inputs

The method requires knowledge of: (1) the mean annual road emissions of a characteristic vehicle in mass per distance traveled, and (2) the total distance traveled during the calendar year by that portion of the total vehicular population characterized by the vehicle. Classification of vehicles was by use: urban or rural driving; and by general type: auto, LDT [GVW less than 6,000 lbs], HDT(II) [GVW of 6,000-10,000 lbs], HDT(III) [GVW of 10,000-19,500 lbs], HDT(IV) [GVW over 19,500 lbs]. Vehicles in a class were categorized by the model year (the model year is the calendar year the vehicle entered the population). This is basically characterization of vehicular emissions by engine type, load, and age. Reference characteristic emissions were obtained for each of the vehicular types and use classifications. The deterioration factor used to account for vehicle age was considered to be solely a function of accumulated road mileage, thus accommodating changes among vehicles in driving usage. It was assumed that vehicular deterioration will not change and that the mileage distribution with age will also remain constant. HDT vehicles were assumed to deteriorate as automobiles, assuming that the increase in mileage traveled is offset by more durable construction.

Three gaseous pollutants were considered, hydrocarbons (based on a hydrogen/carbon ratio of 1.85 to 1.00), carbon monoxide, and nitrogen oxides (as NO_2). Emissions from evaporative sources and crankcase blowby were presumed to consist entirely of hydrocarbons.

Rural driving was characterized by hot start 45 mph (average route speed) operating conditions; urban driving, by cold start 25 mph (average) operating conditions. The relationships among the various operating conditions are themselves independent of mileage.

REFERENCE AUTOMOTIVE EMISSIONS*

Type	Value	1962	1963-1967	1968-1969	1970	1971-1974	1975-1990
NO_2 - exhaust	gm/mile	5.757	5.757	5.757	5.757	5.757	0.960
	ppm	1500	1500	1500	1500	1500	250
CO - exhaust	gm/mile	87.234	87.234	35.103	23.000	23.000	11.500
	%	3.7	3.7	1.5	1.0	1.0	0.5
HC - exhaust	gm/mile	5.678	5.678	3.428	2.200	2.200	0.611
	ppm	456	456	275	176	176	49
HC - evaporative	gm/mile	2.767	2.767	2.767	2.767	0.490	0
HC - crankcase	gm/mile	3.151	0	0	0	0	0

*Concentration values are based on exhaust volume of 70.68 standard cubic feet/mile and pollutant densities of 16.33 gm/scf for hydrocarbon, 33.11 gm/sfc for carbon monoxide, and 54.30 gm/scf for nitrogen dioxide.

Emissions are for federal composite cycle.

2. Outputs

National or regional gaseous pollutants emitted from on-the-road gasoline powered vehicles.

3. Resolution

Annual national or regional.

4. Validation

None.

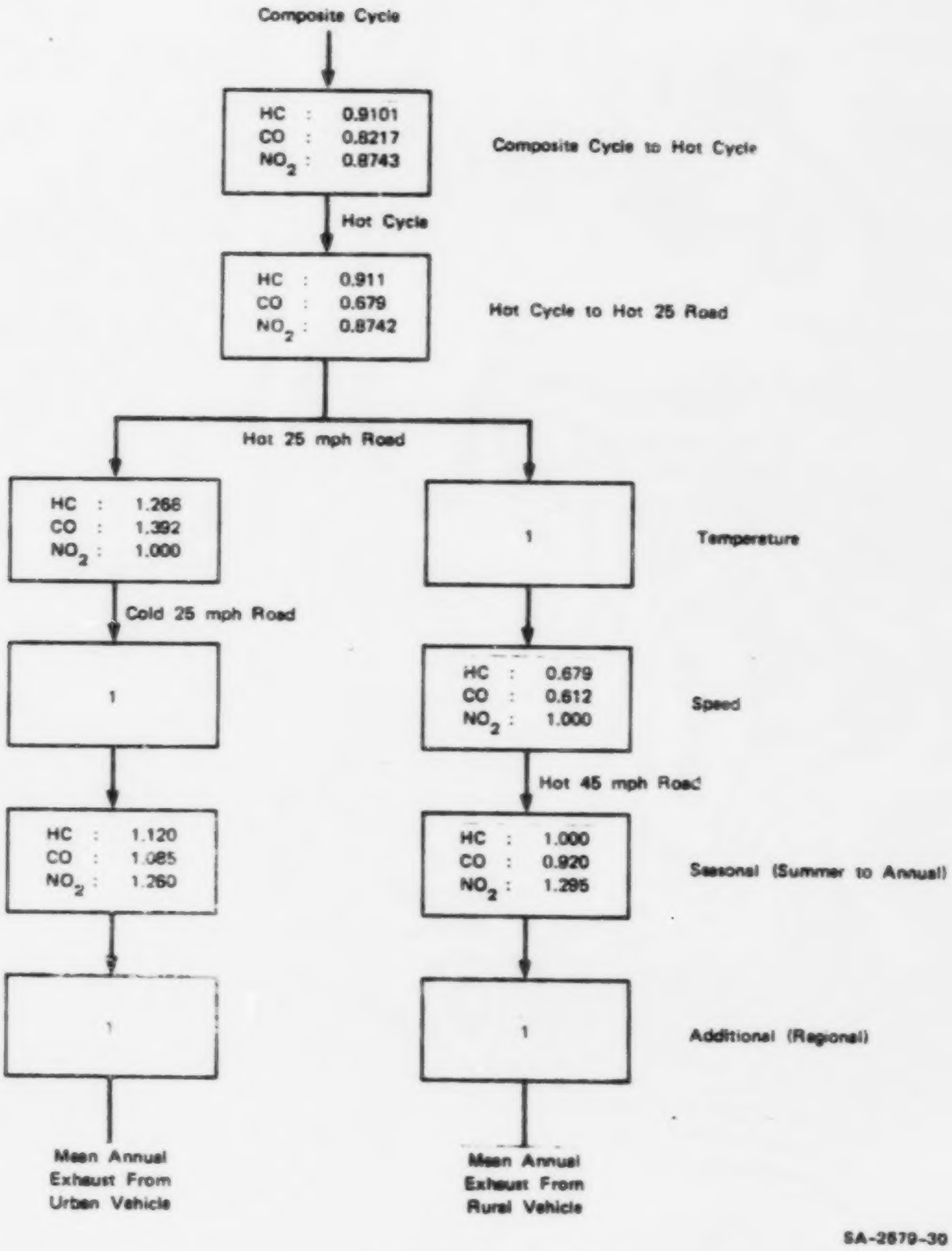

FIGURE B-6 EXHAUST EMISSION FLOW DIAGRAM

EMISSION MODELS CHECKLIST

Input Data Requirements

	Within Program	User Supplies	From AP-42	Proxies/Comments
Vehicle Emission Factors				
-By model year	x	x		
-By size class	x	x		Uses vehicle mix for year of interest in study
-By power plant	x	x		
-Deterioration factor	x	x		
Vehicle Operating Modes				
-Hot/cold start		NP		
-Route average	x	NP		Average rural and urban routes
-Link average		NP		
-Mode-by-mode		NP	NP	
Traffic Features				
-Vehicle mix		NP		
-Engine operating time		NP	NP	
-Vehicle miles traveled	x	x	NP	
-Fuel consumed		NP	NP	
Spatial Distribution				
-Links		NP	NP	
-Grinds		NP	NP	
-Area	x		NP	

NP = No provision

Output Available

Pollutants	
-CO	Yes
-HC	Yes
-NO_x	Yes
-Particulates	No

Availability of Program Documentation

	Yes	No
Included in report		x
Referenced in report		x
Language	NP	
Equipment	NP	

Validation/calibration: None

Time resolution: Annual

Spatial resolution: National or regional

XIV NORTHERN RESEARCH AND ENGINEERING

The Potential Impact of Aircraft Emissions Upon Air Quality. M. Platt, R. C. Baker, E. K. Bastress, et al., Northern Research and Engineering Corp., Cambridge, Mass., 02139, Rept. APTD-1085, December 29, 1971.

A. Author's Abstract

Three categories of emissions were presented: aircraft operations, non-aircraft airport operations, and airport surroundings. In general, each of the sources in these categories can be accurately represented as either point, line, or area sources of time-dependent strength (i.e., emissions per unit time). However, to reduce the complexity of analysis in this study, each emission source is represented by one or more continuous point sources of constant strength over the time period being considered. Each point source is a specific location within the airport or its environs. The strength Q of a point source was evaluated as the total emissions E associated with the point during the time period, divided by the length T of the period.

B. Summary

1. Aircraft Operation

The modes of operation of a typical aircraft which were considered in this study have been established as: (1) approach, (2) landing, (3) taxi [after landing and before take-off], (4) idle and shutdown, (5) maintenance, (6) start-up and idle, (7) idle at runway, (8) take-off, (9) climb-out, and (10) fuel venting.

Operational modes

(4) idle and shutdown
(6) start-up and idle
(5) maintenance
(7) idle at runway

are characterized by pounds of pollutants per aircraft class. The total is calculated by using characteristic times periods for each mode for each aircraft class.

Operational modes

(3) taxi
(1) approach
(9) climb-out
(2) landing
(8) take-off

are characterized by pounds of pollutants per aircraft class. Distribution of traffic among runways, average taxi times, characteristics of the airport under study, and the times and positions along representative flight paths are used to calculate the amount and distribution of the pollutants.

Operational mode

(10) fuel venting

is characterized by total pounds of hydrocarbon per aircraft class and is associated with a point source at 600-meter altitude in take-off.

2. Automobile Travel

Automobile travel within the airport is characterized by a constant emission of pollutant per automobile per unit automobile travel. The total emissions due to automobile operation for a time period were calculated using:

a. Average travel per automobile within the airport

b. Fraction of automobiles entering the airport per passenger

c. Average number of passengers per aircraft

d. Aircraft activity data.

The first two items are considered characteristic of the airport, while the third item is considered characteristic of an aircraft class.

The total emissions were distributed along the airport roadway system, which in addition to highways, included roads within the parking areas. The distribution is accomplished by locating point sources at stations which divide each roadway into a number of equal segments. The emissions of each segment were equally divided between the two bounding stations. This resulted in the same type of distribution as would be obtained for trapezoidal integration of a uniform line source of emissions.

Service vehicle emissions were calculated in an approximate manner as 50% of automobile emissions. They are then included in the distribution of the automobile emissions.

3. Model Sensitivity

The mathematical model of airport emissions and the dispersion of those emissions used to predict pollutant concentrations involves two categories of physical parameters:

a. Meteorological parameters, which consist of atmospheric stability, wind speed, wind direction, mixing height, and for short-term calculations, wind persistence.

b. Source parameters, which consist of the strength and location of emission sources with respect to a receptor.

Parameters in the first category were the subject of a sensitivity analysis, with parameters in the second category investigated indirectly in the analysis of control techniques.

4. Accuracy of the Model

Airport emissions are modeled by a large number of continuous point sources of constant strength distributed throughout the airport. This results in two limitations on the validity of the model. First, the model is limited to time periods that are much larger than characteristic times of individual aircraft activity. Second, the model is limited to receptors that are not in close proximity to the emission sources. Since an airport has many emission sources which would be best represented as lines or areas, the assumption of point sources results in an important limitation of the model.

In providing a check of the results obtained using the model, a comparison was made with emissions and concentrations reported for Los Angeles International Airport. While the emissions for carbon monoxide are in excellent agreement, agreement for the other pollutants is poor. The aircraft emissions of particulates, nitrogen dioxide, and total hydrocarbons for Los Angeles International Airport are greater than those obtained using the model by factors ranging up to 6.7 for particulates. Since the activity data were similar for the two cases, the disagreement can be traced directly to the emission factors.

Concerning the other pollutants, it is significant that agreement is so good for carbon monoxide which can be measured most accurately in engine emission tests and so poor for the other pollutants where different measurement techniques can give very different results.

The measured concentration of carbon monoxide is a factor of 2.8 larger than the analytical value. It is felt that the imprecision with which the surroundings were modeled is the likely cause for this discrepancy (for instance, emissions of automobiles on roadways adjacent to the airport not directly included in the model). Therefore, concentrations due to aircraft emissions alone should be predicted more accurately than concentrations due to all emissions.

EMISSION MODELS CHECKLIST

Input Data Requirements

	Within Program	User Supplies	From AP-42	Proxies/Comments
Vehicle Emission Factors				
-By model year		NP		
-By size class	x	x		
-By power plant	x	x		
-Deterioration factor		NP		
Vehicle Operating Modes				
-Hot/cold start		NP		
-Route average		NP		
-Link average		NP		
-Mode-by-mode	x	x	NP	
Traffic Features				
-Vehicle mix		x		
-Engine operating time	x	x	NP	
-Vehicle miles traveled		x	NP	
-Fuel consumed		NP	NP	
Spatial Distribution				
-Links		x	NP	
-Grinds		x	NP	
-Area		x	NP	

NP = No provision

Output Available

Pollutants	
-CO	Yes
-HC	Yes
-NO_x	Yes
-Particulates	Yes

Availability of Program Documentation

	Yes	No
Included in report		x
Referenced in report	x*	
Language	NP	
Equipment	NP	

Validation/calibration: Los Angeles Airport - 1970 data

Time resolution: 1 hour

Spatial resolution: Airport boundary

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* M. Platt, K. M. Chug, and R. D. Siegel, "Computer Program for the Air Quality Analysis of Airports" (NREC Report No. 1167-2), Northern Research and Engineering Corporation, Cambridge, August 1971.

XV ONTARIO DEPARTMENT OF THE ENVIRONMENT

Information System Descriptive Manual, Air Management Branch, Department of the Environment, Province of Ontario, Canada, January, 1971.

A. Author's Abstract

None given.

B. Summary

The Toronto emissions-inventory methodology considers three source categories: (1) major intense and discontinuous sources (point and line sources); (2) numerous minor sources (area sources); and (3) sources beyond the grid system boundary.

If emissions are greater than 100 lbs per day, the source is considered a point source; otherwise, its emissions are included in area source calculations. The 100 lbs per day criterion may be modified. The Toronto area is divided into 1 kilometer grid squares for area sources, with point sources located on a 5 × 5-kilometer grid to a tenth of a kilometer.

Area sources include emissions from motor vehicles, shipping, railroads, aircraft, and gasoline storage, from space heating and waste disposal of apartments, schools and universities, industrial and commercial sources, and public buildings, and from space heating of residential dwellings. All minor sources within one grid square are summed, and the total is distributed evenly over that square. Line sources are treated as special cases of area sources.

Sources beyond the grid boundary are treated as providing a flux through the border, with assigned source strength and initial vertical distribution. These parameters maintain constant values along the length of the border.

The five pollutants considered are sulfur dioxide, nitrogen oxides, particulates, carbon monoxide, and hydrocarbons. Provision is made for sources which, under certain conditions, must switch from their regularly used fuel to another type, thus changing their emission patterns. The information system is designed to accept new data and can modify old data. The capability exists to modify classes of emissions by a fixed percentage.

1. Automotive Emissions

Roadway emissions are divided into five classes: (1) superhighway (line source), (2) other highway, (3) major artery, (4) residential, and (5) business street. Information is collected such as the vehicle count per day for all roads in each grid square (for residential streets a count of 500 is assumed, slightly higher for residential streets with large apartment buildings), and road lengths in each grid square. Yearly emission quantities are found by multiplying the vehicle count per day by road length and by 365, and then applying the emission factor appropriate to the emission class. The hourly or daily emissions are computed using the appropriate diurnal, daily and seasonal factors that have been tabulated.

2. Point and Other Area Source Emissions

Patterns for point source operations, process and nonprocess, were developed based on days of the week in operation and the number of shifts per day. Seasonal and daily space heating variations for both point and area sources were developed using degree day fluctuations, with hourly variations derived from natural gas demand records over 24-hour periods during different seasons. Other area source emission variations were determined in a similar fashion, based upon usage or frequency variation data.

To obtain hourly emissions from the total annual amount of pollutant, the procedure outlined below is applied. The annual total is:

a. Adjusted by a seasonal factor. Depending on the season, one of four seasonal percents (which add to 100) is mulitplied by the annual pollutant total and then divided by 25,

b. Adjusted to a daily rate, by dividing by 365,

c. Adjusted for day of week, using one of the seven percentages associated with a particular day, and

d. Adjusted for weather if a heating emission. For area sources, the factors depend on dwelling type and fuel type. For point sources, fuel combustion emission are adjusted by a space heating percent. This is done by multiplying by the amount of the degree day total and dividing by the degree year total.

e. Only area sources also adjusted by hour of the day. A table of diurnal codes, each containing 24 numbers which add to 100, are applied so that emissions are spread over the hours of the day, based on the components of the code.

C. Model Availability

As stated earlier, the Toronto emissions inventory methodology was developed by the Department of the Environment, Ontario Province, Canada. The emission model is in the form of a computer code, but it is not generally available for public dissemination. Accordingly, the model can only be obtained through a formal request to the Department.

XVI PACIFIC ENVIRONMENTAL SERVICES

Controlled Evaluation of the Reactive Environmental Simulation Model. L. G. Wayne, A. Kokin, and M. I. Weisburd, Final Report, Pacific Environmental Services, Inc., Contract No. 68-02-0345, prepared for Environmental Protection Agency, EPA R4-73-013a, February, 1973.

A. Author's Abstract

The development and validation of an operational version of the Reactive Environmental Simulation Model (REM) were completed. REM was specifically designed to handle large chemical mechanisms to assess the impact on air quality of air pollution control devices, fuels, propulsion systems, stationary sources, and transportation systems where thorough evaluation of emissions, emission constituents and reaction rates are required. The version delivered to the U.S. EPA under this contract contains a mechanism involving 32 reactions, 12 accumulating species, and 12 nonaccumulating species. Larger or smaller mechanisms, also, can be readily inserted into REM for specified purposes.

REm is based on a Lagrangian moving coordinate system which enables the numerical simulation of the chemical reactions that take place in a parcel or column of air moving along a dynamic wind trajectory. The trajectory approach gives REM considerable flexibility and is adaptable for use in a number of practical operational situations. These include short-term air quality forecasting; analysis of the impact of sources of air pollution at various designated locations on the air quality at specified receptor points; interpolation of contaminant concentrations and dosages at locations not covered by air monitoring stations, and control strategy evaluations.

REM contains such user features as reverse and forward trajectory routines; automatic and objective interpolation from input emission inventory, meteorological and air quality data bases; a chemical dynamics routine capable of accommodating mechanisms based on elementary chemical reactions; and automatic estimation of mixing depth and solar irradiance based on input of local weather and sun angle data.

REM has attained a running time which makes it cost-effective for practical use. On an IBM System 370/155, the real-time-to-simulation ratio for the 31-step mechanism is 150:1; for carbon monoxide alone it is 3000:1; for some of the shorter mechanisms available it should run more than 300:1. The program, also, is user-oriented in that it provides simple input procedures, user documentation, receptor point and time-of-day selectivity, flexibility in treating specific problems, and ability to conveniently select any of an infinite number of trajectories on any number of days of interest. The modular construction of REM, also, makes it easy to add, replace, or delete individual modules. REM can be used as an unlimited receptor point model and to chronicle emission inputs contributing to the air quality at any receptor point.

The validation record of REM over a large number of runs may be summarized as follows:

- CO, less than a factor of 2 in more than 80% of the comparisons; 40% agreement within one part per million.
- O_3 within a factor of 2, 75% of the comparisons.
- NO, within a factor of 2, 75% of the comparisons; 90% agreement within 0.02 ppm.
- NO_2, within a factor of 2, 60% of the comparisons.

The shapes of predicted time profiles of contaminant concentrations are generally similar to those observed at air monitoring stations.

The ease and economy at which REM can be utilized under a variety of data availability situations make potential improvements in accuracy and application possible on a cost-effective basis.

B. Summary

1. Treatment of Source Emissions

A subroutine (module) of the REM program computes emissions of NO, CO, and reactive and less reactive hydrocarbons from freeway and street traffic. Emissions of NO and reactive and less reactive hydrocarbons are calculated for stationary area sources. All urban grid squares are chosen as four square-mile blocks, although the kilometer may also be used as the standatd. Emissions within these squares are viewed as essentially uniform and continuous.

Inputs to the module include time, position of the pollutant column, the distribution of daily traffic on streets and freeways, emission factors, and diurnal usage curves. Traffic and grid system distributions and diurnal curves for the Los Angeles Basin are taken from the emissions treatment developed by Systems Applications, Inc., a review of which has previously appeared in this appendix.

Traffic emission are computed as a function of time by applying the emission factors for the respective pollutants to the traffic levels at the air parcel location, qualified by the daily traffic usage curve. Area source emissions as a function of time are found by applying a constant diurnal usage curve to grid system distributions of average hourly pollutant emissions.

2. Module Method of Operation

Following is the procedure by which pollutants are injected into an air parcel.

1. Initialization (background concentration).

2. Traffic distribution curves are evaluated.

3. The grid in which the trajectory point lies is found.

4. The three closest adjacent grids are found (those with the closest midpoints).

5. The distance from the trajectory point to each grid midpoint is calculated.

6. Is the trajectory point on the midpoint of the grid square in which it lies? If yes, go to step 9; if no continue.

7. The contribution to the parcel from each traffic grid for each pollutant is calculated (the contribution is inversely proportional to the square of the distance from the trajectory point to the grid midpoint).

8. If area sources are to be added, the area source contribution from each grid square for each pollutant is calculated (inversely proportional to the distance squared). Skip to step 11.

9. The traffic contributions of the trajectory grid only are calculated.

10. If area sources are to be added, the area source contributions of the trajectory grid only are calculated.

11. The traffic and area contributions are then modified by the appropriate diurnal usage curves and added.

C. Model Availability

A computer listing of the emission inventory is included in the supplemental User's Guide of the report.

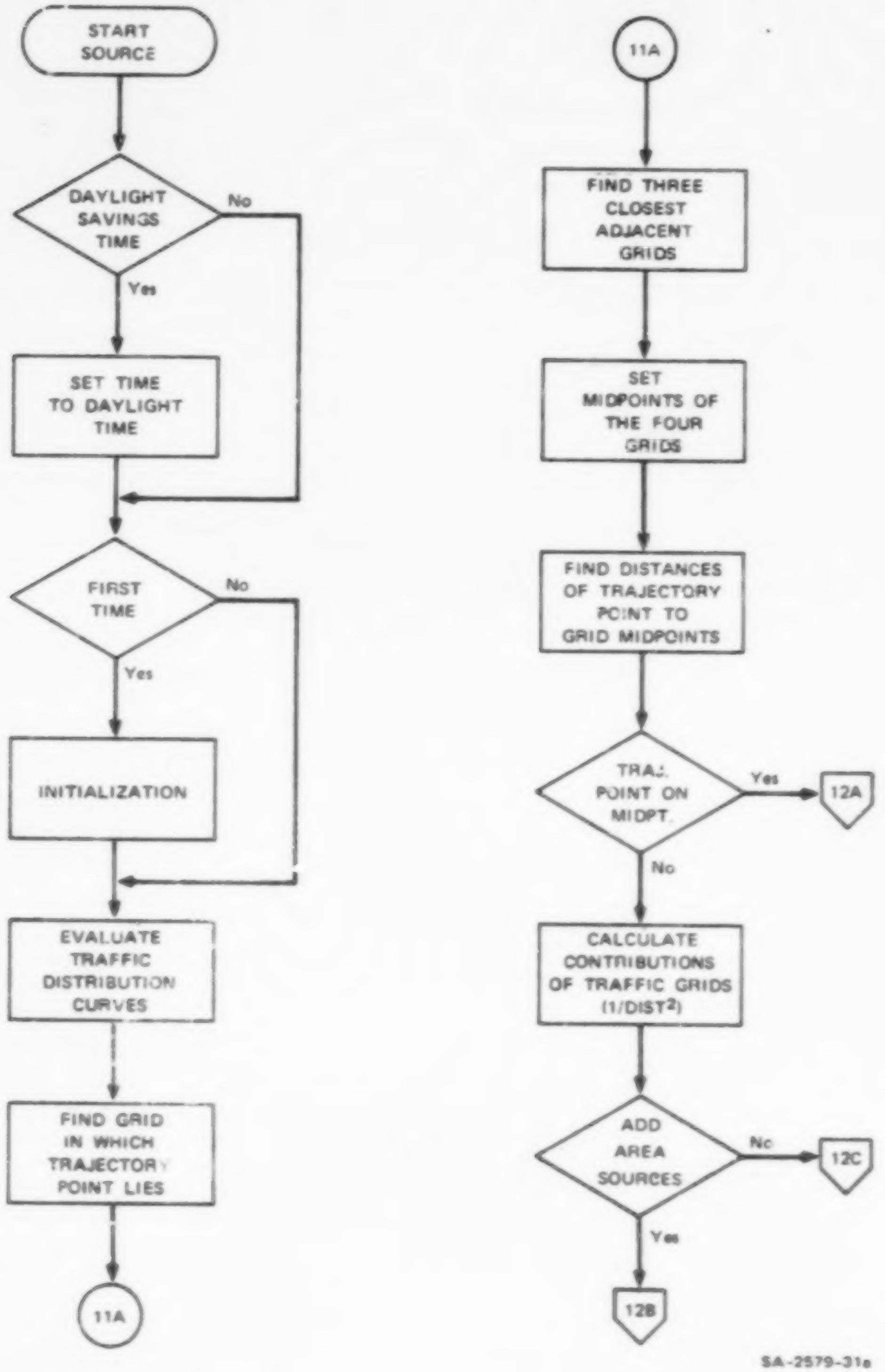
START SOURCE
DAYLIGHT SAVINGS TIME
No
Yes
SET TIME TO DAYLIGHT TIME
FIRST TIME
No
Yes
INITIALIZATION
EVALUATE TRAFFIC DISTRIBUTION CURVES
FIND GRID IN WHICH TRAJECTORY POINT LIES
11A
11A
FIND THREE CLOSEST ADJACENT GRIDS
SET MIDPOINTS OF THE FOUR GRIDS
FIND DISTANCES OF TRAJECTORY POINT TO GRID MIDPOINTS
TRAJ. POINT ON MIDPT.
Yes
12A
No
CALCULATE CONTRIBUTIONS OF TRAFFIC GRIDS (1/DIST2)
ADD AREA SOURCES
No
12C
Yes
12B
SA-2579-31a

FIGURE B-7 FLOW OF SOURCE SUBROUTINE

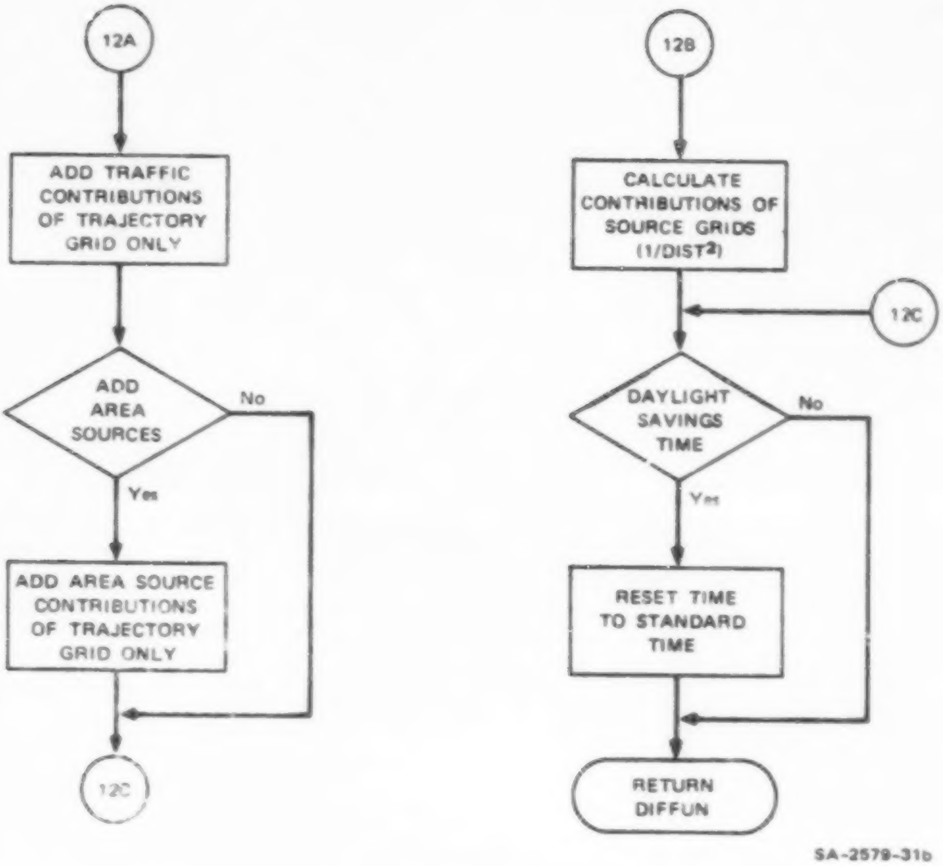
12A
ADD TRAFFIC CONTRIBUTIONS OF TRAJECTORY GRID ONLY
ADD AREA SOURCES
No
Yes
ADD AREA SOURCE CONTRIBUTIONS OF TRAJECTORY GRID ONLY
12C
12B
CALCULATE CONTRIBUTIONS OF SOURCE GRIDS (1/DIST²)
12C
DAYLIGHT SAVINGS TIME
No
Yes
RESET TIME TO STANDARD TIME
RETURN DIFFUN
SA-2579-31b

FIGURE B-7 FLOW OF SOURCE SUBROUTINE (concluded)

XVII RUTGERS UNIVERSITY

Comparison of Air Pollution from Aircraft and Automobiles (Project Eagle). C. Bright et al., Rutgers University, New Brunswick, New Jersey, AD713913, September, 1970.

A. Author's Abstract

None given.

B. Summary

Emissions from either aquadrome or roadway areas are considered to constitute a surface of randomly distributed multiple sources. This surface is assumed to be a uniform area source with respect to a receptor located a variable distance downwind from the edge of the aquadrome or roadway segment.

Emissions are calculated by assuming aircraft passenger load factors and the number of passengers per commuting automobile. The number of passengers and vehicle road or air miles from each source to central locations are used to determine the total number of auto and aircraft miles. This mileage is used to calculate emissions using the following emission factors:

MOTOR VEHICLE EMISSIONS
(gm/passenger mi)

	1970[*] Emissions	1970[†] Actual	1975[*] Goals	1975[†] Actual	1980[*] Goals	1980[†] Actual
Hydrocarbons	8.81	12.10	0.40	8.51	0.20	3.11
Carbon monoxide	38.95	72.35	8.87	45.24	3.79	18.87
Nitrogen oxides	10.35	6.84	0.73	7.84	0.32	3.52
Particulates	0.40	0.47	0.08	0.38	0.02	0.17

TOTAL AIRCRAFT VEHICLE EMISSIONS: APPROACH, CRUISE, TAKE-OFF AT 100% LOAD FACTOR
(gm/passenger mi)

	1970	1975	1980
Hydrocarbons	0.3696	0.3696	0.3696
Particulates	1.0107	1.0107	1.0107
Carbon monoxide	1.4717	1.4717	1.4717
Nitrogen oxides	0.8151	0.8151	0.8151

---

[*] Based on HEW estimates of emission-controlled vehicles that will be in production at that date.

In converting the grams per vehicle mile to grams per passenger mile, an average automobile passenger occupancy of 1.24 persons is used. For aircraft, occupancy load factors of both 100% and 50% were considered. The 100% load factor was demonstrated to be feasible in the Project Eagle Study. As shown in the tabulation above, the values for aircraft in grams per passenger mile is computed allowing separate emission rates for approach, cruise, and take-off. In converting the grams per vehicle mile to grams per passenger mile, a trip length of 20.8 miles is used for the 53-passenger aircraft. This 20.8-mile trip length represents the average air passenger distance traveled in an urban air transportation system during 7 a.m. to 9 a.m. and 4:30 p.m. to 6:30 p.m. between Manhattan and the 11 transportation centers in Connecticut (Bridgeport, New Haven, and Stamford), New Jersey (Linden/Rahway, New Brunswick, Paterson and Newark), and New York (Farmingdale, Hempstead, Mt. Vernon, and White Plains).

[†] Based on a methodology considering automobile age and vehicle usage corresponding to automobile age. This procedure is currently being used by the National Air Pollution Control Administration, Durham, North Carolina.

EMISSION MODELS CHECKLIST

Input Data Requirements

	Within Program	User Supplies	From AP-42	Proxies/Comments
Vehicle Emission Factors				
-By model year	x	x		By mix on road for year of study interest
-By size class	x	x		
-By power plant	x	x		
-Deterioration factor	x	x		
Vehicle Operating Modes				
-Hot/cold start		NP		
-Route average	x	x		
-Link average		NP		
-Mode-by-mode		NP	NP	
Traffic Features				
-Vehicle mix		NP		
-Engine operating time		NP	NP	
-Vehicle miles traveled	x	x	NP	
-Fuel consumed		NP	NP	
Spatial Distribution				
-Links		NP	NP	
-Grinds		NP	NP	
-Area	x	x	NP	

NP = No provision

Output Available

Pollutants	
-CO	Yes
-HC	Yes
-NO_x	Yes
-Particulates	Yes

Availability of Program Documentation

	Yes	No
Included in report		x
Referenced in report		x
Language	NP	
Equipment	NP	

Aircraft emission factors based on 1968 NRC work - no program given.
Auto emission factors based on NAPCA data.

Validation/calibration: None

Time resolution: 4 hours

Area: Tri-State (Connecticut, New Jersey, and New York)

XVIII SACRAMENTO REGIONAL AREA PLANNING COMMISSION

General Inventory of Air Pollution Sources and Emissions.
The Air Pollution Threat, Sacramento Regional Area Planning
Commission, NTIS No. PB191382, October, 1969.

A. Author's Abstract

The Sacramento Region has three major sources of pollution: transportation, agriculture waste burning, and other stationary sources. The report was directed at estimating the amounts of organic gases, carbon monoxide, nitrogen oxide, sulfur dioxide and aerosols that are emitted from their sources. The predominant emission is carbon monoxide with an estimated 1,215 tons being produced daily. Carbon monoxide is produced mainly from gasoline powered motor vehicles. The other emissions that are produced in the region are organic gases (267 tons/day), nitrogen oxide (87 tons/day), aerosols (46 tons/day), and sulfur dioxide (9 tons/day).

B. Summary

An emission inventory of the Sacramento, California region was compiled for organic gases, carbon monoxide, nitrogen oxides, sulfur dioxide, and aerosol emissions. Sources were classified as transportation, agricultural waste burning, and stationary sources.

The transportation category is divided into gasoline and diesel powered motor vehicles, railroads, and aircraft. Pollutant emission is based on estimates of the different fuels used. Gasoline usage is based on an estimate of 1.1 gallons per day per person. Emission factors for gasoline and diesel powered vehicles take into account existing smog control devices.

Agricultural emissions arise from agricultural waste burning and crop processing, the latter being included with stationary sources. In the Sacramento region 15% of total agricultural waste is burned. Emission figures represent tons of emissions produced on a straight daily average. Seventy-five percent of the burning is done from October to February, with emission figures higher during this season.

Stationary sources include agricultural product processing, where 1% of the total amount of crops processed is estimated as the amount of particulate lost due to processing. Annual figures are divided by the number of days per year to obtain daily values. Emissions from petroleum handling result when tank trucks, service station tanks, and automobile tanks are filled. A daily figure for gallons handled is found by multiplying the population of a region by the estimate of gallons per day per person used. Emissions estimates for solvent use, metal, and mineral processing, and chemical manufacturing are obtained from regional agencies. To estimate emissions from the incineration of solid waste, the total amount of refuse burned daily is found by assuming an average figure of 2 lbs per person per day and multiplying by the population. This amount is divided between municipal dump burning (75%) and backyard burning (25%). Backyard burning is further divided into incinerator, open, and landscape burning. Heating of homes and industrial fuel use are the main sources of emissions from fuel combustion. Natural gas figures are obtained from the utility company, and bottled gas is accounted for either directly or by increasing the yearly utility company figure by 10%. Total daily gas is divided between domestic (75%) and industrial (25%) sources.

C. Model Availability

A computer program for the emissions model is not included.

XIX STANFORD RESEARCH INSTITUTE

A Practical, Multipurpose Urban Diffusion Model for Carbon Monoxide. F. L. Ludwig, W. B. Johnson, A. E. Moon, and R. L. Mancuso, Stanford Research Institute, Menlo Park, California, September, 1970.

A. Author's Abstract

This report describes the development and current status of a receptor-oriented diffusion model that can be applied to urban areas to give the following outputs: (1) carbon monoxide (CO) concentration isopleths for a given set of meteorological conditions and times of day, (2) sequences of hourly CO concentrations at specific locations for given sequences of meteorological conditions, and (3) climatological summaries of CO concentration for specific locations if a historical record of meteorological data is available. The model can be used to obtain the frequency distributions of concentrations averaged over various time intervals for specific hours of the day or days of the week.

B. Summary

Because nearly all urban carbon monoxide emissions are from internal combustion vehicles, the model assumes emissions to be at ground level. Furthermore, the emissions within each segment are assumed to be uniformly distributed. The inventory of vehicular emissions has two components: (1) primary network link emissions from vehicles traveling on the network of major arterial streets and freeways, and (2) secondary background emissions from vehicles traveling over the less densely traveled local and feeder streets.

The primary network links for which the emissions are computed are the sections of major arterial streets and freeways between intersections with other major arterials and freeways. The average length of the links on the primary network is approximately one mile, although the links may be much shorter in densely traveled downtown areas, and more widely spaced in outlying areas. Traffic volumes on links vary hour-by-hour over a day and are different for weekend days than for weekdays. Further, there are smaller seasonal variations. Highway engineers and planners average these variations into a quantity that they call average daily traffic (ADT). For use in the synoptic model, the emissions must be expressed as hourly averages, so the average daily traffic is expressed as a function of time. The amount taken to occur within any given hour is based on the hourly distribution of trips compiled by the traffic study agencies of many areas.

To calculate the contribution of the emissions from traffic links within the five closest segments, the links are first identified with the segments through which they pass. Then the length of the link that lies within a given segment is determined. The emissions within the four segments farthest from the receptor are calculated by a different technique than that used for the closer segments.

Before other computations begin, the city is divided into a grid of one-mile (1.6 km) squares. The traffic link data are used to determine the average daily CO emission in each of these squares. This is accomplished by dividing each link into small increments, less than 0.08-km long. The average daily emission from each of these small pieces is determined by assuming emissions are spread uniformly along the link. Then, the emissions from all the small pieces of link within a square are added together to give total daily emissions for that square. This total is paired in the computer memory with the coordinates of the point at the center of the square. These calculations are done only once for the city.

A trapezoidal grid system is used in the four outer emission segments. As the location of the receptor changes or the wind direction changes, these trapezoidal grids are superimposed on different parts of the fixed city emission grid described in the preceding paragraph. The average emissions at each point on the trapezoidal grid are determined by interpolation between the values at the points on the fixed grid. The average of the emission values determined for the points on the trapezoidal grid defines the emission rate for the segment.

Historical link-volume data are obtained from traffic departments in the cities, towns, and counties in the region being studied. Because traffic varies according to seasonal, weekly, and daily cycles, an observation of volume for one day must be adjusted for the weekly and seasonal fluctuations. The resultant corrected value is recorded as the average daily traffic (ADT) for that location.

The number of vehicle-miles traveled on streets not represented by the primary network is computed from an estimate of the total vehicle-miles traveled in the area and the total vehicle-miles on the links of the primary network. The local street mileage is taken to be the difference between the two.

Link speeds for use in the emission rate calculation are determined from averages of peak and off-peak travel hours on various kinds of route facilities. Speed data were obtained from the traffic survey.

For most locations, the peak traffic hour speeds were taken as equal to 80% of the off-peak speeds. Peak-hour speeds were generally assigned to the four heaviest traffic hours of the day.

The emission rate, e (g/vehicle-mile), is determined from the equation

$$e = c\,S^{\beta}$$

where S is the average speed over the link, in mi/hr, and c and β are constants. For vehicles in use before exhaust control systems, $c = 1121$ and $\beta = -0.849$, as determined by Rose et al. (1969)[1] from observations on a number of vehicles in several locations. For autos reflecting the level of emission controls mandated for 1968-70, one hundred thirty-nine emission values were calculated from emission data presented by Beckman et al. (1967)[2] and from actual observations of speeds, speed changes, and stops for a variety of road types and traffic congestion conditions. Regression analysis was used to examine the relation between emissions and average speed, both with and without controls. The following power function proved to be the best fit for 1969 model year automobiles:

$$e = 245\,S^{-0.48}$$

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[1] A. H. Rose and W. D. Krostek, "Emission Factors," U.S. Dept. of Health, Education and Welfare, National Air Pollution Control Administration, p. 5, 1969.

[2] E. W. Beckman, W. S. Fagley, and O. Sarto, "Exhaust Emission Control by Chrysler--The Cleaner Air Package," *Air Pollution--1967 (Automotive Air Pollution)*, Hearings before the Subcommittee on Air and Water Pollution of the Committee on Public Works, United States Senate, Ninetieth Congress, First Session, Part 1, pp. 411-424, 1967.

Consideration of emission control progress yielded the emission model for 1980 and later model year automobiles:

$$e = 34\ S^{-0.48}\ .$$

C. Model Availability

The APRAC model is fully documented in a recent report by Mancuso and Ludwig[3]. The program is available in two versions: one for the SRI CDC 6400 computer and another for the EPA IBM 360/50.

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[3] R. L. Mancuso and F. L. Ludwig, "User's Manual for the APRAC-1A Urban Diffusion Model Computer Program," CRC/EPA Contract No. CAPA-3-68(1-69),SRI Project 8563, Stanford Research Institute, Menlo Park, California, 1972.

EMISSION MODELS CHECKLIST

Input Data Requirements

	Within Program	User Supplies	From AP-42	Proxies/Comments
Vehicle Emission Factors				
-By model year	x	x		Average CO of vehicle mix for year of study interest
-By size class	x	x		
-By power plant	x	x		
-Deterioration factor	x	x		
Vehicle Operating Modes				
-Hot/cold start		NP		
-Route average		NP		
-Link average		x		Speed and distance
-Mode-by-mode		NP	NP	
Traffic Features				
-Vehicle mix		NP		
-Engine operating time		NP	NP	
-Vehicle miles traveled		x	NP	
-Fuel consumed		NP	NP	
Spatial Distribution				
-Links		NP	NP	
-Grinds		x	NP	
-Area		x	NP	

NP = No provision

Output Available

Pollutants	
-CO	Yes
-HC	No
$-NO_x$	No
-Particulates	No

Availability of Program Documentation*

	Yes	No
Included in report		
Referenced in report		
Language		
Equipment		

Validation/calibration: Calculated data were low compared with CAMP-observed data in St. Louis

Time resolution: 1 hour

Spatial resolution: Radial segments-22.5° out to 16 km from receptor point

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* See Section C, Model Availability

XX STANFORD RESEARCH INSTITUTE

Procedures for Estimating Highway User Costs, Air Pollution, and Noise Effects. D. A. Curry and D. G. Andersen, NCHRP Report 133, prepared by Stanford Research Institute, 1972.

A. Author's Abstract: None given

B. Summary

Because the researchers were unable to locate data in the proper form, the approach to the estimation of emissions is to compute emissions for a vehicle of a particular type and characterize the emissions from that vehicle as "typical" of the vehicles that will be built during the next few years. The assumption is that the control technology will not change the patterns.

The emission estimating procedure assumes that during the next few years vehicles will achieve carbon monoxide and hydrocarbon control through use of the engine mondification package and a catalytic afterburner, and will achieve nitrogen oxides control through exhaust gas recirculation.

Emission characteristics of a vehicle using the assumed type of engine modification package were obtained for a vehicle manufactured by the Chrysler Corporation. Because most manufacturers are using this type of control, it is assumed that the vehicle is typical in that regard.

The emissions for stopping and changing speeds were computed under the assumption that slowing down and speeding up would occur under constant acceleration conditions. The emissions added due to speed changes were computed by applying the emission characteristics of the test vehicle to the pattern of speed changes analyzed elsewhere in the report and by characterizing the results by the best straight line that could be drawn through the emission values plotted against volume to capacity (v/c) ratio for each type of facility.

The reference emissions provide an estimate of the pounds of each pollutant generated by travel over the analysis segments if all of the traffic consisted of automobiles meeting the exhaust emission control requirements for the 1969 model year. The table below gives the emission limits in grams per mile and their relative ratios for various model years as used in the conversion procedure (the ratios do not always track the emission limits exactly, owing to changes in test procedures). These relative values were combined with the fraction of the vehicle population represented by each model year as predicted by averaging the fractions for the years 1966-1970.

AUTOMOBILE EMISSION LIMITS FOR VARIOUS MODEL YEARS

	Actual or Permissible Emission (gm/mi)			Emission Factor Used (1970=1.0)	
Model Year	HC	CO	NO_x	HC and CO	NO_x
1967 and earlier	13.6	117	4.0	3.5	1.0
1968 and 1969	5.1	59	4.0	1.5	1.0
1970	3.4	39	4.0	1.0	1.0
1971-72	3.4	39	4.0	1.0	1.0
1973-74	3.4	39	3.0	1.0	0.75
1975	0.41	3.9	3.0	0.1	0.75
1976-79	0.41	3.9	0.4	0.1	0.1
1980 and later	0.20	2.0	0.2	0.05	0.05

Use of the conversion factor assumes that the future controls will reduce emissions proportionally for all operating conditions. Use of a catalytic afterburner for control of carbon monoxide and hydrocarbons will result in emissions that approximate this assumption.

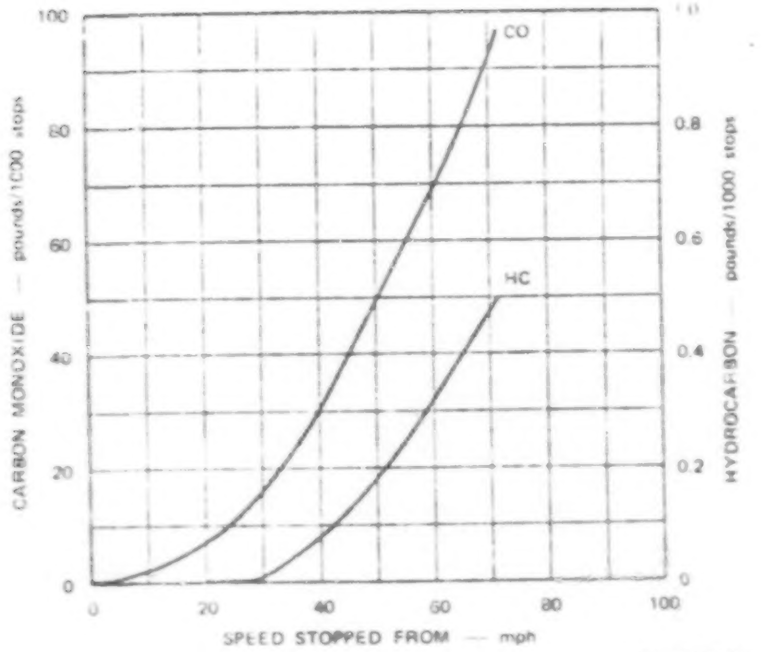
The emissions for single-unit gasoline trucks were estimated to be 2.5 times those of the reference automobile under all conditions.

The last step was to incorporate a degradation factor for the predicted increase in vehicle emissions due to wear, derived from data of Rose and Krostek.[1] The degradation factor increases at a decreasing rate with average mileage drive, and hence with age:

Vehicle Age (yr)	Degradation Factor
0	1.00
1	1.05
2	1.12
3	1.18
4	1.20
5	1.22
6	1.23
7	1.24
≥ 8	1.25

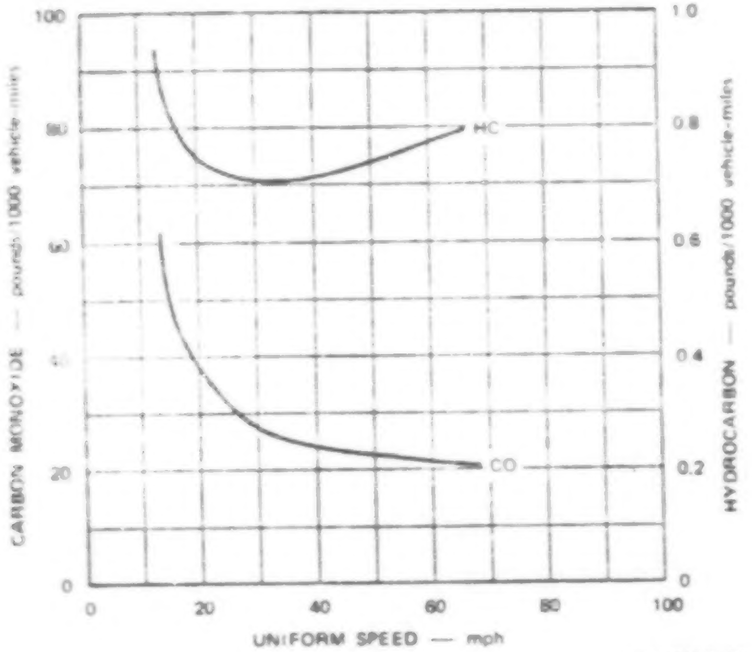
---

[1] A. H. Rose, Jr. and W. D. Krostek, "Emission Factors," Department of Health, Education, and Welfare, June, 1969.



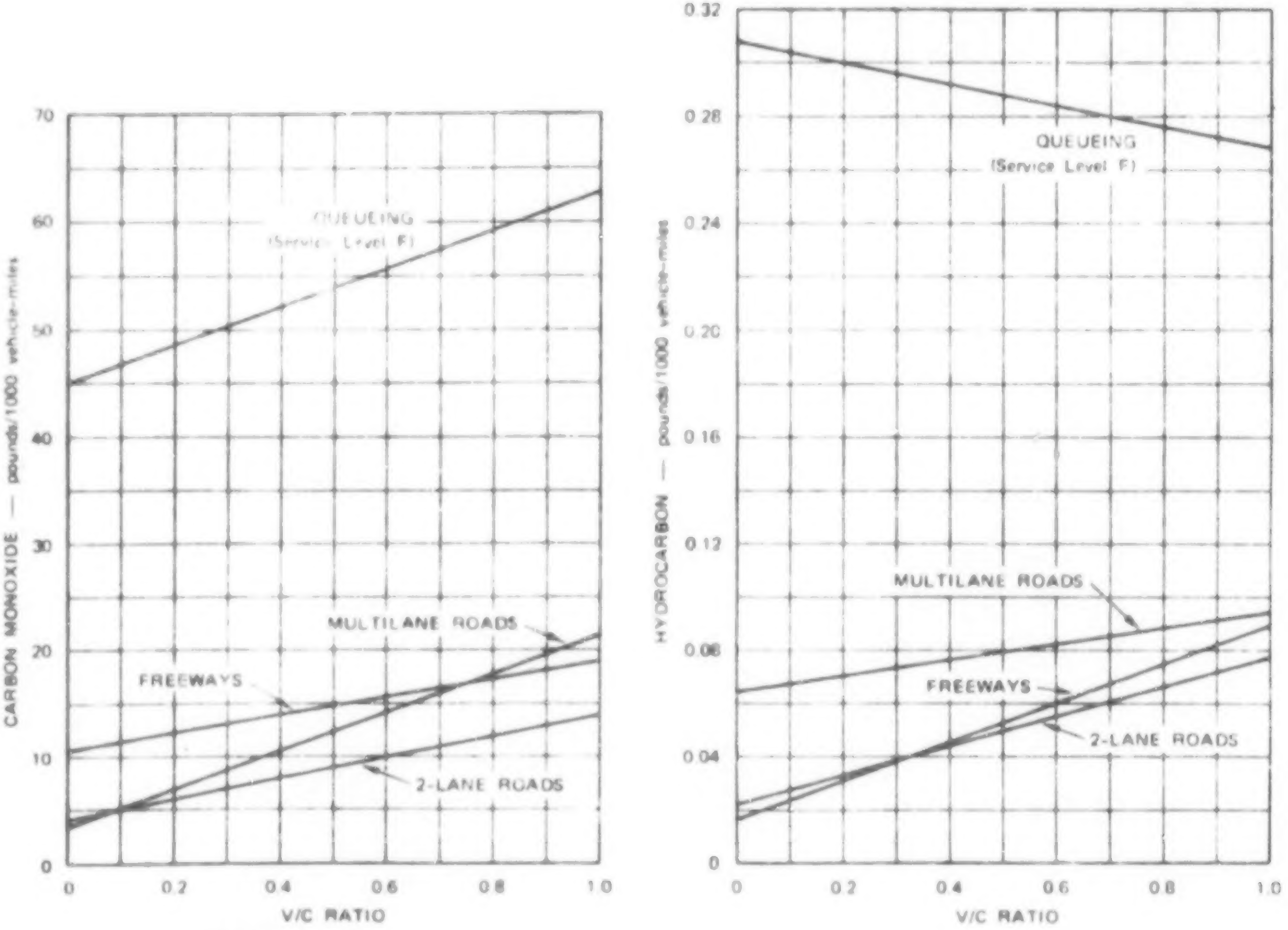
SA-2579-32

FIGURE B-8 AUTOMOBILE HYDROCARBON AND CARBON MONOXIDE EMISSIONS ADDED PER 1,000 STOPS



SA-2579-33

FIGURE B 3 AUTOMOBILE HYDROCARBON AND CARBON MONOXIDE EMISSIONS PER 1,000 MILES OF DRIVING AT UNIFORM SPEED

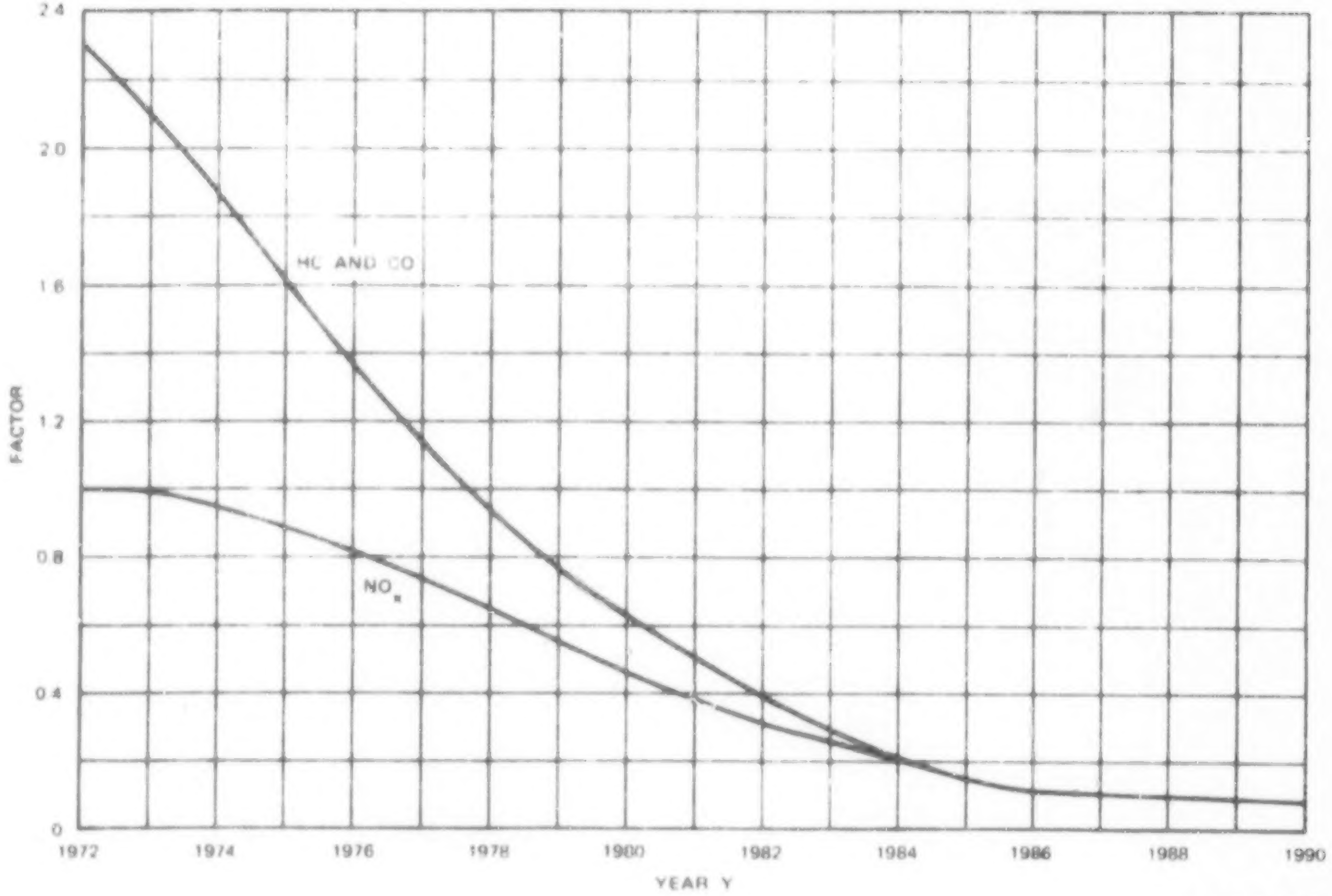


CARBON MONOXIDE

HYDROCARBON

SA-2579-39

FIGURE B-10 AUTOMOBILE EMISSIONS ADDED FROM SPEED CHANGES PER 1,000 VEHICLE-MILES



SA-2579-36

FIGURE B-11 FACTOR TO CONVERT REFERENCE YEAR EMISSIONS TO EMISSIONS IN YEAR Y

EMISSION MODELS CHECKLIST

Input Data Requirements

	Within Program	User Supplies	From AP-42	Proxies/Comments
Vehicle Emission Factors				
-By model year	x			Based on 1969 reference auto, conversions supplied for other years
-By size class	x			
-By power plant		NP		
-Deterioration factor	x			
Vehicle Operating Modes				
-Hot/cold start		NP		
-Route average		NP		
-Link average		NP		
-Mode-by-mode		x	NP	
Traffic Features				
-Vehicle mix		x		
-Engine operating time		NP	NP	
-Vehicle miles traveled		x	NP	
-Fuel consumed		NP	NP	
Spatial Distribution				
-Links		x	NP	
-Grinds		NP	NP	
-Area		NP	NP	

NP = No provision

Output Available

Pollutants	
-CO	Yes
-HC	Yes
-NO_x	No
-Particulates	No

Availability of Program Documentation

	Yes	No
Included in report		x
Referenced in report		x
Language	NP	
Equipment	NP	

Validation/calibration: None

Time resolution: 1 hour

Spatial resolution: Link

XXI STANFORD RESEARCH INSTITUTE

A Preliminary Study of Modeling The Air Pollution Effects From Traffic Engineering Alternatives. F. L. Ludwig, R. C. Sandys, and A. E. Moon, Stanford Research Institute, Menlo Park, California, Air Pollution Control Association Journal, Vol. 23, No. 6, pp. 499-504, June, 1973.

A. Author's Abstract

Three separate mathematical models were combined to calculate the changes in carbon monoxide (CO) concentrations that might result from traffic engineering changes. The three models used were: (1) The Dynamic Highway Transportation Model (DHTM) which relates traffic flow patterns to physical parameters and traffic signal characteristics of a network; (2) an emission model that predicts CO emissions from traffic flow parameters such as number of stops, idling time, etc.; and (3) the APRAC-1A urban diffusion model which calculates CO concentrations from source distributions and meteorological factors. The composite model was applied to traffic in downtown Chicago for a specific set of meteorological conditions. Results are compared for two traffic signal control schemes. In those blocks where concentrations were highest, the model indicates a 20% reduction is possible through improved traffic signal controls. The model should be useful for testing other traffic control measures.

B. Summary

Moon[1] has presented a methodology for calculating the amount of CO generated by a "reference" automobile under four conditions: idling,

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[1] D. A. Curry and D. G. Andersen, "Procedures for Estimating Highway User Costs and Air and Noise Pollution Effects," Final Report, Highway Research Board Project 708, Stanford Research Institute, Menlo Park, California, 1971.

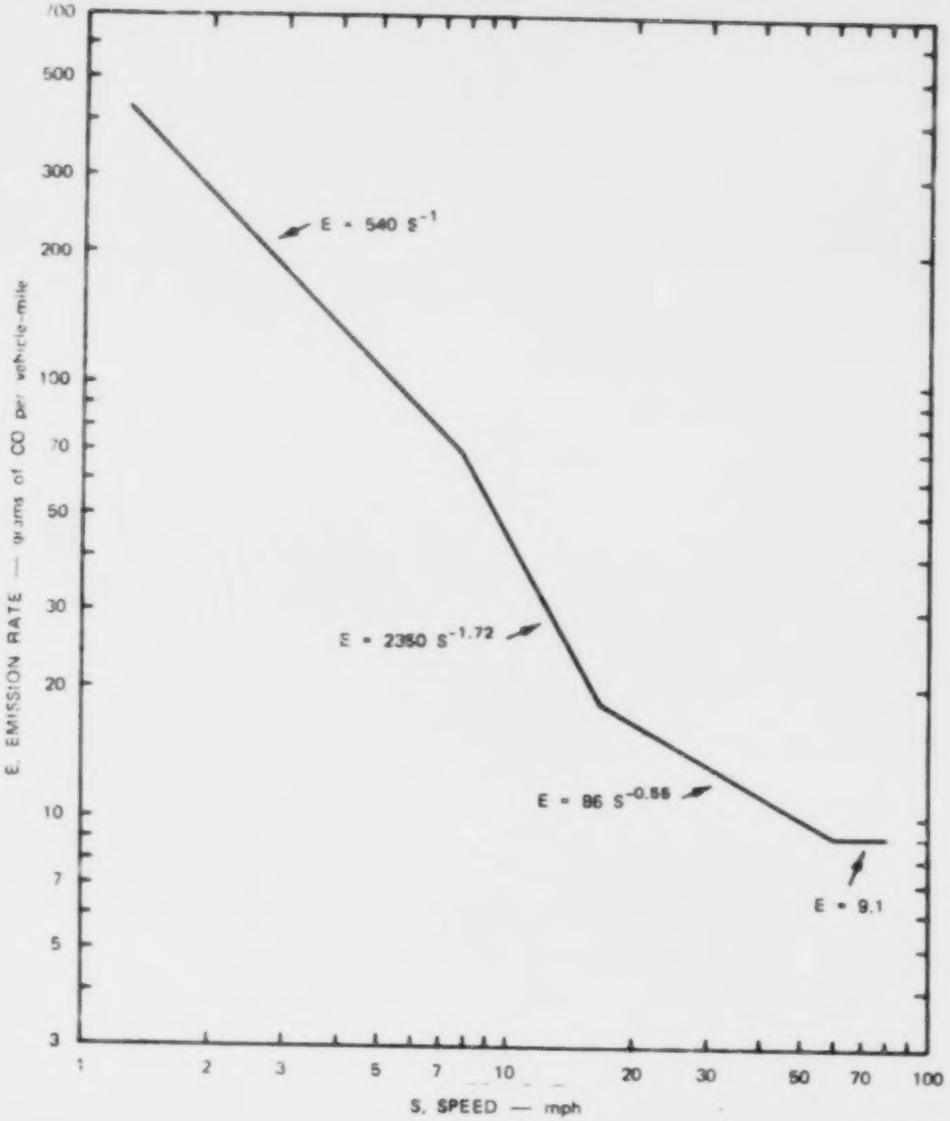
steady cruising, stopping, and starting. The third and fourth conditions can be combined, with the results expressed as the amount of CO emitted per vehicle stop. Because of continual changes in the pollution control devices required for cars, and the changing mix of vehicle-model years, it is necessary to convert emissions for "reference" cars to averages for a particular year. The appropriate conversion factors have been provided in Reference 1.

According to Moon, 0.15 gram per second (gm/s) of CO are released by an idling vehicle. The amount of CO released by a vehicle traveling at a steady speed is a function of that speed. Figure 1 shows an approximation of the function; the curve has been fitted with exponential functions to simplify the calculations. At the low speeds, below about 7 or 8 mph, the curve shown is based on the assumption that a slowly moving vehicle emits CO at the same rate as an idling vehicle; thus, the emissions per vehicle-mile will be inversely proportional to the speed. The emissions for each vehicular stop (and subsequent start) are an exponential function of the steady driving speed from which the stop was made.

A factor is used to convert emissions of CO from a vehicle made in the reference year (1968) to emissions for years after 1971. The factor accounts for the mixture of vehicles manufactured in different years, based on national averages of vehicle life expectancy. It is based on existing legislation for the 1970 to 1975 era and on expected further limitation on emissions through 1980, and assumes no retrofit requirements.

Moon's emissions model can calculate the emissions of CO on a given street segment, given:

1. Number of vehicle-miles of steady-speed driving on the link
2. The speed achieved during steady-speed operation
3. The number of stops and starts during the hour
4. The number of vehicle-seconds spent stopped and idling.



SA-2579-a1

FIGURE B-12 RELATIONSHIP BETWEEN CARBON MONOXIDE EMISSIONS AND STEADY-SPEED DRIVING

275<

The Dynamic Highway Transportation Model can provide the above items of information. For this study, an intermediate computer program was written to accept the magnetic tape output of the DHTM and create a punch card deck for input to the APRAC-1A Diffusion Model; this is not the most efficient method of treating the problem.

This model is offered for central business district applications. For the outlying streets, the method using the formula developed by Rose and Krostek[2] to relate emissions to average speeds and traffic volumes is considered adequate.

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[2] A. H. Rose, Jr. and W. D. Krostek, "Emission Factors," Department of Health, Education, and Welfare, June 1969.

EMISSION MODELS CHECKLIST

Input Data Requirements

	Within Program	User Supplies	From AP-42	Proxies/Comments
Vehicle Emission Factors				
-By model year	x	x		1968 Reference; factored to later years
-By size class		NP		
-By power plant		NP		
-Deterioration factor		NP		
Vehicle Operating Modes				
-Hot/cold start		NP		
-Route average		NP		
-Link average		NP		
-Mode-by-mode		x >	NP	Starts; stops; idling; steady-state speed; vehicle miles/link
Traffic Features				
-Vehicle mix		NP		
-Engine operating time		x	NP	
-Vehicle miles traveled		x	NP	
-Fuel consumed		NP	NP	
Spatial Distribution				
-Links		x	NP	
-Grinds		NP	NP	
-Area		NP	NP	

NP = No provision

Output Available

Pollutants	
-CO	Yes
-HC	No
$-NO_x$	No
-Particulates	No

Availability of Program Documentation

	Yes	No
Included in report		x
Referenced in report		x
Language	NP	
Equipment	NP	

Validation/calibration: None

Time resolution: 1 hour

Spatial resolution: Intersection

XXII SYSTEMS APPLICATIONS, INC.

(1) Contaminant Emissions in the Los Angeles Basin--Their Sources, Rates, and Distribution. P. J. Roberts, P. M. Roth, and C. L. Nelson, Appendix A., "Development of a Simulation Model for Estimating Ground Level Concentrations of Photochemical Pollutants," Systems Applications, Inc. Report No. 71 SAI-6, Contract No. CPA 70-148, prepared for the Environmental Protection Agency, March 1971.

(2) Extensions and Modifications of a Contaminant Emissions Model and Inventory for Los Angeles. P. J. Roberts, M. Liu, S. D. Reynolds, and P. M. Roth, Appendix A, "Further Development and Validation of a Simulation Model for Estimating Ground Level Concentrations of Photochemical Pollutants," Systems Applications, Inc., Report No. R73-15, Contract No. 68-02-0339, prepared for the Environmental Protection Agency, January, 1973.

A. Author's Abstract

(1) Perhaps the most tedious and mundane aspect in the development and validation of a simulation model of reaction and dispersion processes in the atmosphere is the compilation of a complete contaminant emissions inventory. Yet, such an inventory is a sine qua non in model validations and, if done properly, the emissions estimates probably constitute the most precise segment of requisite input data. Contrast, for example, the relatively low magnitudes of errors in emissions estimates with the imprecision of wind speed and direction estimates, both at the surface and aloft, as well as with the uncertainties in estimates of the variation in mixing depth with location and time. Furthermore, as emissions inventory need be carried out but once to serve as an adequate representation of a region, whereas meteorological data must be collected for each validation day, and for the purposes of this modeling venture, represented through hourly variation in wind field and mixing depth. It thus seemed wise

to put a considerable effort into the establishment of an accurate emissions inventory for the Los Angeles Basin.

Particular emphasis was placed on developing a detailed representation of the spatial and temporal traffic distribution in the Basin, as vehicular emissions account for approximately 97% of CO; 85% of reactive hydrocarbon, and 62% of NO_x emissions. Attention was also given to those sources which, while responsible for only a small proportion of emissions on an area-wide basis, contribute heavily to pollutant concentration levels in their own locale--airports, power plants, and refineries. In this Appendix, we present in detail the emissions inventories developed for the major moving and fixed sources of pollution in the Los Angeles Basin.

(2) During the last months of 1970, we prepared a pollutant emissions inventory for the Los Angeles Basin for use in the modeling of the transport, diffusion, and reaction of atmospheric contamination. Pollutant sources were grouped into five categories--automobiles (and other motor vehicles), aircraft, power plants, refineries and distributed fixed sources. Emissions rates for a 2x2-mile grid system covering the Basin were compiled for nitrogen oxides, carbon monoxide, and hydrocarbons. Temporal variations in emissions rates were also determined. The complete inventory is reported in "Contaminant Emissions in the Los Angeles Basin--Their Sources, Rates, and Distribution," by P.J.W. Roberts, P. M. Roth, and C. L. Nelson (1971).

Early in 1972, we had the opportunity to make a number of modifications and extensions for the emissions inventory. The changes which affected all segments of the original inventory, were motivated by a variety of factors, but most heavily by a desire to improve the accuracy or the resolution of the inventory, or the correct errors. It is the purpose of this report to document all modifications and extensions that were implemented. In general, this report is segmented similarly to its predecessor, the exceptions being that (1) changes applicable to all portions of the inventory are included in an introductory general section and (2) the one modification to the refinery inventory as a matter of convenience, is included in the section dealing with distributed fixed sources. Finally, we wish to point out that only changes are reported here; we have not attempted to present a final version of the inventory, either in summary or in detail, in this document. One must read both this report and the original to construct the complete inventory.

B. Summary

The emissions model developed by SAI considers both fixed and moving sources of air pollution in the Los Angeles Basin. Fixed sources are characterized as area sources, with the exception of point source power plant emissions, which are treated as volume sources. Both automotive and aircraft emissions are distributed over an array of grid squares. Concentrations of carbon monixide, hydrocarbons and nitrogen oxides are predicted, using hourly emissions estimates.

1. Treatment of Automotive Emissions

Automotive emissions are estimated for 2.0x2.0-mile grid squares and are assumed to be attributable to exhaust, crankcase leakage (blow-by) and evaporation. The Federal Driving Cycle (FDC) is adopted.

a. Exhaust Emissions

Surface Streets. Average emission rates for surface streets are estimated by calculating

$$Q_i^a(t) = y(t)Q_i^c + [1-y(t)]Q_i^h$$

where y(t) equals the fraction of cars started at time t that are "cold-started" (superscript c); the relation between cold-start and hot-start (superscript n) emissions is:

$$Q_i^h = Q_i^c \left[\frac{zP_i^h + (1-z)T_i}{zP_i^c + (1-z)T_i} \right]$$

where z = fraction of vehicle registration that are automobiles

P_i^n, P_i^c = hot-running and cold-start auto emission rates

T_i = emission rates from trucks and buses

Both Q_i^c and Q_i^h are based on the FDC, which is defined to simulate a trip having an average speed of about 19.6 mph.

A variation exists in the emissions rate due to the non-uniform distribution of cold vehicle starts during the day. To account for this, a correction factor, $\beta_i(t)$, is formulated.

An integral representing the average emissions rate for each vehicle is derived, relating the emissions from a vehicle during a time interval after a cold-start, ϵ_i^c, to those after a hot-start, ϵ_i^h. Functional forms for ϵ_i^c and ϵ_i^h are established, giving a linear decrease in ϵ_i^c during the first 7-1/2 minutes of operation and a constant emissions rate thereafter, equal to ϵ_i^h. The integral is approximated by an expression for the average emissions rate at the midpoint of a 15-minute time interval that assumes that the trip start time is uniform during the time interval. The correction factor is defined as this approximation divided by the average emissions rate.

This treatment considers the effect of vehicle start variation only for the period 6 a.m. to 9:23 a.m. The "midday bump" and evening rush hour variations are not considered because the model was not validated for that time period. Also, it should be noted that large quantities of data are needed to properly evaluate $\beta_i(t)$. Pertinent data include driving patterns in an area, trip length, average speed, time between trips, emissions data as functions of time for both hot-

and cold-starts, etc. Since large quantities of this data are not generally available, the authors have made simplifying assumptions.

The correction factor is

$$\beta_i(t) = \frac{E_i^s(t)}{Q_i^s(t)}$$

where $Q_i^s(t)$ is the average emissions rate as defined previously, and

$$E_i^s\left(t_n\right) = \frac{\frac{c_{n-2}}{30}\,\varepsilon_i^h + c_{n-1}\left[\left(1-y_{n-1}\right)\varepsilon_i^h + y_{n-1}\,\bar{\varepsilon}_i\right] + \frac{c_n}{2}\left[\left(1-y_n\right)\varepsilon_i^h + y_n\tilde{\varepsilon}_i\right]}{\frac{c_{n-2}}{30} + c_{n-1}\,\frac{c_n}{2}}$$

where n = a fifteen-minute time interval

$E_i^s\left(t_n\right)$ = average emissions rate of species i evaluated at the midpoint of time interval n

c_n = total number of trips started in a time interval

y_n = ratio of cold-starts to total starts during a time interval

$\varepsilon_i^h(t)$ = emission from a vehicle during a time interval after a hot-start

$\bar{\varepsilon}_i$ = average emissions rate of species i from an automobile over the time period between 7-1/2 and 22-1/2 minutes after a cold start

$\tilde{\varepsilon}_i$ = average emission rate of species i from an automobile over the time period between zero and 7-1/2 minutes after a cold-start

The ε_i^h and ε_i^c values are derived on the basis of the FDC, and $\bar{\varepsilon}_i$ and $\tilde{\varepsilon}_i$ follow from these. Values of c_n are based on an analysis of data by Kearin et al. (1971)*, where the weekday was segmented into

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* D. H. Kearin, R. L. Lamoureux, B. C. Goodwin, "A Survey of Average Driving Patterns in Six Urban Areas of the United States: Summary Report", Report TM-(L)-4119 Vol. 7, System Development Corp., Santa Monica (January 1971).

eight time periods, each with an assigned constant value of y.

The total emissions from surface streets for a particular grid square are

$$E_i^s(t) = \frac{1}{60} Q_i^s(t) d_\ell^s(t) M^s \beta_i(t)$$

where $d_\ell^s(t)$ = fraction of daily nonfreeway traffic count assignable to an hourly period

M^s = nonfreeway vehicle mileage per day for the grid square in question

Values of $d_\ell^s(t)$ are based on an average of 32 randomly selected streets (the sample being stratified according to the magnitude of daily traffic flow), the counts on individual streets being weighted in proportion to the magnitude of traffic flow on the street. Traffic counts were taken from state and city data.

Freeways. In calculating freeway emissions, all vehicles are assumed to be hot-running. It has been found that average emissions rates for freeways in Los Angeles correlate well with average route speed alone, although many other factors influence these rates.

Freeway emissions rates for species i for a particular grid square are given by

$$E_i^f(t) = \frac{1}{60} \left\{ n_f(t) \alpha_i [\bar{v}(t)] + n_s(t) \alpha_i [\bar{v}_s(t)] \right\}$$

$$\alpha_i = a_i (\bar{v})^{b_i}$$

where $\bar{v}_f, \bar{v}_s$ = average speed in the fast and slow directions, respectively

n_f, n_s = number of vehicle miles driven per hour in the fast and slow directions, respectively

c_i = hot-running emissions rate of species i

a_i, b_i = empirically determined constants

"Fast" and "slow" refer to an assignment of names to the two opposing directions of flow on a freeway.

$$n_f = \frac{N_\ell^f}{1+x}$$

$$n_s = \frac{\left(N_\ell^f\right)x}{1+x}$$

$$N_\ell^f = d_\ell^f M^f$$

where d_ℓ^f = fraction of daily freeway traffice counts assignable to an hourly period

M^f = freeway vehicle mileage per day for a grid square

$x = n_s/n_f$

The average vehicle flow as a function of time for both directions on all freeways in the Los Angeles Basin is calculated from 15-minute count data for a 24-hour period at 31 locations. Values of x are computed using these data. Average freeway speed as a function of time for both freeway directions was obtained from state division of highways data.

To determine the constants a_i and b_i, average emissions rates for hot-running conditions at a known average speed are necessary. These rates were estimated in the same manner as those for surface streets. Also required are the slopes of emissions rate/average speed curve. Data for these are very scarce, and the best such data available are somewhat out of date (less than 50% of the vehicles on the road in

September, 1969, are represented by the test group). Correlations based on the data give estimates of average emissions rates at high speeds under hot-running conditions that appear to be rather low. The authors decided to modify the values, basing their modifications on the premise that automobile manufacturers design their systems with the expectation that they will be tested at low average speeds. Thus, it may be expected that average emissions rates at low speeds have decreased more rapidly from year to year than rates at high average speeds. Since there is no data on which to base estimates of revised slopes b_i, they are estimated using two points, the hot-running emissions rates at 19.6 mph and the rates at 60 mph, the latter computed from

$$Q_i^h(60) + 1/3 \left[Q_i^h(19.6) - Q_i^h(60) \right]$$

where Q_i^h (19.6) are the FDC values, modified for hot-running conditions, and $Q_i^h(60)$ are computed from the data described above. The factor one-third is purely a guess and could range from 0.1 to 0.5.

Total Exhaust Emissions. Total vehicle emissions for a particular grid square are given by

$$E_i(t) = E_i^f(t) + E_i^s(t)$$

b. Crankcase Emissions

It is estimated that 15% of all automobiles are not equipped with PCV devices. This study uses a figure of 0.7 gm/mile for the average vehicle in the Los Angeles Basin.

c. Evaporative Losses

Evaporative losses are the sum of fuel tank losses and carburetor losses, and involve only hydrocarbons. The authors assume that these losses occur mainly during the hours 7 a.m. to 7 p.m. PDT, and that they are distributed evenly over this period. Evaporative emissions in each square are assumed to be proportional to the number of nonfreeway vehicle miles in that square.

$$\begin{pmatrix}\text{evaporative}\\ \text{emissions for}\\ \text{square } i,j\end{pmatrix} = m_{ij}\,\frac{\begin{pmatrix}\text{number of}\\ \text{automobiles}\\ \text{registered}\end{pmatrix}\begin{pmatrix}\text{evaporative}\\ \text{losses}\end{pmatrix}}{\begin{pmatrix}\text{total nonfreeway}\\ \text{vehicle mileage}\end{pmatrix}}$$

where m_{ij} equals thousand of nonfreeway vehicle miles per day driven in square ij.

2. Treatment of Aircraft Emissions

Hourly emissions from airport operations are classified as arising from ground and airborne operations. For each class of aircraft it is assumed that pollutants are emitted at a uniform rate during each of five operating modes; the amount of contaminants injected into a cell is thus proportional to the length of the flight path in that cell. Aircraft emissions are treated as volume sources, well-mixed in their cells, and are assumed to occur at a uniform rate over each 1-hour time period. Emissions indices measured from one aircraft are assumed representative of all aircraft of that class.

a. Ground Operations Emissions

Ground operations are assigned three modes of operation: taxi, landing, and take-off. The taxi mode includes taxi between runway and satellite upon landing, between satellite and end of runway and awaiting clearance for take-off, and idle at satellite. The landing mode includes emission from touchdown on the runway to turn-off from the runway, with the take-off mode being the reverse.

Ground operation emissions rates into ground cell $ij\ell$ for an hourly period are

$$Q^{k}_{ijm,\ell,m=1} = \frac{10^{-3} d_{\ell} a_{ij}}{K} \sum_{u=1}^{7} n_u M_u \sum_{g=1}^{3} f^{k}_{gu} C_{gu}$$

where i,j are indices for the x,y coordinates

m is an index for the z coordinates (= 1 for ground cells)

ℓ is an index for the hourly period

k refers to the type of pollutant (CO, HC, NO, and NO_2)

g refers to ground operation mode (taxi, landing, and take-off)

u refers to aircraft class (long-range jet transport, medium-range jet transport, business jet, turboprop transport, piston engine transport, piston engine utility, and turbine engine helicopter

$Q^{k}_{ijm\ell}$ = emissions rate

d_{ℓ} = fraction of total daily flights in an hourly time period

A_{ij} = fraction of airport area belonging to a ground cell

K = 60 (min/hr)

n_u = number of flights per day of aircraft class u

M_u = average number of engines per aircraft class u

f^{k}_{gu} = pounds of pollutant k emitted per 100 lbs of fuel consumed by aircraft class u operating in mode g

C_{gu} = pounds of fuel consumed per engine of aircraft class u operating in mode g

b. Flight Operations Emissions

The modes of operation for airborne operations are an approach mode and a climb-out mode. It is assumed that arrival and departure rates within each time period are equal; that aircraft follow straight-line flight paths while in approach and climb-out modes; and that ascent and descent angles for all aircraft at a particular airport are equal to those of the aircraft class having the highest fraction of total operations at that facility. Other assumptions are that flight paths originate and terminate at the most frequently used runway at each airport; that a fixed proportion of aircraft of a given class arrive and depart from each airport, and that an unknown temporal distribution of flight operations at an airport may be represented by the temporal distribution from another airport having a similar mix of aircraft by class.

Emissions rates for airborne flight operations are given by

$$Q^{k}_{ijm\ell} = \frac{10^{-3} d_{\ell} P_{ijm}}{K} \sum_{u=1}^{7} n_u M_u f^{k}_u C_u \frac{t_u}{t'_u}$$

where t_u = time spent in descent from inversion height to touch-down by aircraft of class u

t'_u = time spent in descent from 3000 feet above ground elevation to touchdown by aircraft of class u

f^{k}_u = pounds of pollutant k emitted by aircraft of class u per 1000 lbs fuel consumed during descent

C_u = pounds of fuel consumed per engine of aircraft of class u during descent from 3000 feet

P_{ijm} = fraction of the length of the flight path assignable to cell ijm

The above equation also describes the emissions rate during climb-out, with the appropriate changes in the definitions of t_u, f^{k}_u, t'_u and C_u.

3. Treatment of Fixed Source Emissions

a. Power Plants

Emissions from point source power plants are distributed evenly as volume sources in the column of cells up to the inversion base, under the assumption that the plume is well mixed in these cells. Since diurnal variations in NO_x emissions were substantial, hourly emissions averages for the two seasons in some plants and for one day in others are used as source strengths and apportioned as described above.

b. Oil Refineries

Refinery emissions are treated as area sources and are assumed to be well mixed in the cell into which they are injected. Total daily emissions for nitrogen oxides and low and high reactivity organic gases and the individual refinery crude capacities were available from the Los Angeles County Pollution Control District. The total emissions are distributed uniformly over 24 hours and in proportion to the crude capacity of each refinery.

c. Distributed Sources

Additional sources are treated uniformly as area sources. Since some of the emissions from these sources are spread over highly populated areas, the modeling area was divided into regions of high and low population density.

Petroleum Marketing, Domestic, Ship and Railroad Emissions--Nitrogen Oxides. It is assumed that half of the total daily domestic emissions and the total daily emissions attributable to petroleum marketing operations occur between 6 a.m. and 6 p.m. PST. Half of the daily ship and railroad emissions are assumed to occur at the Port of Los Angeles. The emissions cited above are distributed uniformly over the high-population grid square. All emission rates are assumed to be uniform between 6 a.m. and 6 p.m. PST.

Incineration--Nitrogen Oxides. The authors assume that the total daily emissions occur between 6 a.m. and 6 p.m. PST, and that emission rates are constant. In Los Angeles County, emissions assignable to a grid square are proportioned to the number of permit units issued for the 5-mile square area containing that grid square. Due to lack of information on the spatial distribution of industrial plants in Orange County, emissions are assumed to be released in the highly populated squares.

Mineral Processing Plants and Metallurgical Plants--Nitrogen Oxides. These emissions are apportioned for each county in the same manner as incineration emissions.

Petroleum Production and Other Industries--Nitrogen Oxides. Petroleum production emissions are also apportioned in the same manner as incineration emissions, but are distributed uniformly over 24 hours. Other industries contribute emissions which are distributed uniformly between 6 a.m. and 6 p.m. PST, mainly over the south central portion of Los Angeles County, with smaller amounts in other areas.

All Fixed Sources--Organic Gases. Organic emissions from petroleum marketing, dry cleaning, degreasing, and other organic solvent users are assumed to be uniformly distributed over the highly populated squares between the hours of 6 a.m. and 6 p.m. PST. Surface painting and coating operations emissions are distributed uniformly between 6 a.m. and 6 p.m. PST in proportion to the number of paint bake oven permits in each square. Petroleum production organic emissions are spread uniformly over 24 hours and in proportion to the number of petroleum processing equipment permit units in each square. Incineration, mineral processing plant, power plant and other industrial organic emissions are not considered significant enough to be included.

All Fixed Sources--Carbon Monoxide. The total fixed source carbon monoxide emissions in the modeling area are considered negligible.

C. Model Availability

Although the emission inventory methodology has been thoroughly discussed and the appropriate equations listed, no operational computer code is included in the report.

XXIII SYSTEM DEVELOPMENT CORPORATION

Development of a Simulation Model for Estimating Ground Level Concentrations of Photochemical Pollutants. M. Weisburd, L. G. Wayne, R. Danchick and A. Kokin, Final Report, System Development Corporation, prepared for Environmental Protection Agency, Contract No. CPA 70-151, January, 1971.

A. Author's Abstract

Modeling photochemical air pollution for simulation on the computer must, at the present time, be based on the limited operational and experimental data available. Computer simulation dictates that the gaps and uncertainties which occur in our present understanding of photochemical pollution be dealt with in order to simulate the photochemical system as a functional whole. All modeling, therefore, must involve the making of assumptions and the application of theoretical considerations. Modeling strategies largely differ in the type and amount of theory applied.

The approach taken by the System Development Corporation (SDC) stays relatively close to the state-of-the-art in that (1) while the conveniences of theoretical mechanisms are necessary in some instances, the modeling is largely based on the operational and experimental data available, (2) the trajectory (and history) of moving air parcels; and (3) the effect of vertical stability (mixing depth).

The basic assumption taken is that the chemical mechanism largely governs, both quantitatively and qualitatively, the ground level concentrations of primary and secondary contaminants at particular times and locations. This accuracy is dependent upon, and is maximized by the ability to follow in a detailed manner the cumulative build-up of pollution in samples of air as they move across the metropolitan area. The 33-step, 25-species mechanism, and the calculation of trajectories based on a dense

network of meteorological stations, contained in the current version of the model, reflect the degree of confidence placed in this approach. The calculation of mixing depth is of similar importance as it affects the concentrations of primary pollutants.

B. Summary

The SDC model is an early version of the REM transformation model, the emissions treatment of which has been previously discussed. It should be noted that an earlier version of the model contained a subroutine to include pollutants from large point sources. However, initial runs of the model with this routine indicated no significant difference in air quality from that obtained using area source emissions alone, although an insufficient number of trajectories were run to conclusively establish the impact of the routine.

1. Sensitivity to Changes in Emission Factors

One sensitivity run consisted of doubling the emission factors for all contaminants. The results were an approximate 20% increase in ozone, no appreciable effect on NO_2, nearly an 11% increase in CO, and a 25% reduction in nitric oxide concentrations. The effect of doubling emission factors must be taken as the doubling of emissions in the immediate vicinity of the trajectory only, as changes in emission factors do not affect the value of background concentrations.

Reduction of the emission factors by one-half decreased ozone concentration at the trajectory terminus by only 1 pphm, CO by approximately 5%, and both oxides of nitrogen by less than half the control values.

The emission factor for nitric oxide alone was increased by 25%, with a negligible effect on concentration.

2. Sensitivity to Changes in Background Contamination

The effect of reducing background contamination was explored in a series of runs using different trajectories. Results confirm that the relative effect differs "substantially" from one location to another.

3. Sensitivity to Changes in the Diurnal Traffic Curve

The diurnal traffic density curve used in the model assumes a peak at 8 a.m. PDT and a constant lower value between 1 p.m. and 6 p.m. PDT. Two runs were made with different trajectories, where the assumed traffic density curve was altered. For one run the curve was shifted so that the morning peak occurred at 7 a.m. PDT, resulting in minimal changes in concentrations from those of the control run. The other case tested utilized a trajectory leading to downtown Los Angeles that was much more directly affected by the morning traffic peak. The curve was shifted by 2 hours, resulting in a 50% reduction in ozone, a one-third reduction in CO, little change in NO_2, and approximately a 100% increase in NO. The effect of change in the curve is highly dependent on trajectory location and time of day.

XXIV TRAVELERS RESEARCH CORPORATION

Sensitivities of Air Quality Prediction to Input Errors and Uncertainties. G. R. Hilst, Proc. of Symp. on Multiple-Source Urban Diffusion Models, Chapel Hill, N.C., APCO Pub. No. AP-86, 1970.

A. Author's Abstract

With the advent of computer-oriented simulation models of the physical and chemical system that produces varying levels of air quality, it is both possible and desirable to assess the model's sensitivities to errors and uncertainties in the input variables. From such analyses, it is possible to derive more explicitly the levels of accuracy that must be observed in the specification of the inputs for source strengths and distributions, wind velocity, horizontal and vertical diffusion rates, and pollutant chemical reactions or physical decay and loss rates, if the air quality predictions derived from these inputs are to remain within useful limits of accuracy and uncertainty.

For the present report, a single case study is utilized to test the sensitivity of the Travelers Research Corporation Regional Model to random and systematic errors in the source-strength input and to systematic errors in the remaining input variables. It has been found that random errors in the source strengths do not produce comparable errors in the air quality prediction. Beyond this, and in order of decreasing sensitivity, the TRC model has been found to be highly sensitive to systematic regional wind-direction errors and moderately sensitive to systematic errors in source-strength estimates, decay or loss rates, and vertical diffusion rates. The model is insensitive to errors in lateral diffusion rates, at least for the multiple-source distribution encountered in Connecticut. These Sensitivities are quantified for the case studied.

The case used for the sensitivity analyses also provided an opportunity to determine the effect of changes in the input variables on the verification of the model, since observations of SO_2 were available from the verification program. Significant improvements in the TRC model verification, over that obtained from the original, independently chosen, input variables, were found when either the source strengths or the decay or loss rates were adjusted appropriately. This result suggests the need for much better understanding of the decay and loss of airborne SO_2.

B. Summary

Using the Travelers Research Center Gaussian plume model, an assessment was made of the model's sensitivity to errors in various input parameters, including misestimates of source strength and positional errors.

1. Source Strength Error

The model was found to be relatively insensitive to large random errors in the specification of source strength. Evidently, among multiple sources random errors tend effectively to cancel each other. Assuming a Gaussian distribution of fractional error in concentration

$$\frac{X_T - X_E}{X_T}$$

where X_T = true value of concentration

X_E = erroneous value of concentration

the range of the fractional error increases by only a factor of 2, while the RMS value of the error in source strength, Q, increases by a factor of 8.

While no systematic error in concentration is introduced by random errors in Q, the standard deviation of concetration error is broadened as random errors in Q increase.

The model was much more sensitive to systematic errors in Q. Since it is prescribed that the concentration, X, is directly proportional to Q, there must be a one-to-one correspondence between systematic errors in Q and errors in X. Thus,

$$\overline{[(X_T - X_E)/X_T]} = \overline{[(Q_T - Q_E)/Q_T]}$$

The standard deviation for systematic error is zero.

3. Positional Error

Mislocation of sources, receptors, etc., automatically invokes errors in all of the input parameters. Therefore, a systematic error in the direction of the general wind field was utilized for the assessment of sensitivity to the compounded errors of position. Noting that the reference values for all input parameters were arbitrarily chosen, results show that mean error is less than or equal to 50% and individual error is greater than 200%. The mean fractional concentration errors are not extreme, but the spread of these errors is.

XXV TRW

Prediction of The Effects of Transportation Controls on Air Quality in Major Metropolitan Areas. Prepared by TRW, Inc., McLean, Virginia, APTD-1363, EPA, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, 27711.

A. Author's Abstract

Transportation data in the form of vehicle miles traveled (VMT) by geographic areas have been used as the basis for calculating emission rates and air quality. The methodology involved:

Step 1. Assignment of VMT and speed to elements of a grid network. This required superimposing a rectangular grid network consisting of one mile squares or one kilometer squares over a base map of the metropolitan area and summation of VMT from each of the individual roadways which may fall within one of the small grids to obtain the total VMT for each element or small grid in the grid network. The speed for each grid of the grid network is obtained by averaging the speeds from each element or roadway within the grid for each element of roadway as a proportioning factor. In this manner the many vehicular sources moving within an individual grid can be represented by a single stationary source, which produces the same amount of emissions, equal to the size of the individual grid. This equivalent source is called an area source because the emissions from the grid or area source are now considered as evenly distributed or evenly produced over the entire area of the individual grid.

Step 2. Use of vehicle emission factors to calculate emissions on a per-grid basis.

Step 3. Conversion of emission rates to pollutant concentration on a per-grid basis by the method of Gifford and Hanna.[1]

Step 4. Application of transportation control strategies to the data base to obtain predicted concentration patterns for each control strategy for the year 1977.

The resulting concentrations are presented graphically as isopleths over a map of the metropolitan area. Pollutants considered were carbon monoxide, hydrocarbons, and oxides of nitrogen, with carbon monoxide being of primary interest.

B. Summary

Transportation data in the form of vehicle miles traveled (VMT) by geographic areas have been used as the basis for calculating emission rates and air quality. The methodology involved:

Step 1. Assignment of VMT and speed to elements of a grid network. This required superimposing a rectangular grid network consisting of one mile squares or one kilometer squares over a base map of the metropolitan area and summation of VMT from each of the individual roadways which may fall within one of the small grids to obtain the total VMT for each element or small grid in the grid network. The speed for each grid of the grid network is obtained by averaging the speeds from each element or roadway within the grid for each time period required, using the VMT along each element of roadway

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[1] S. R. Hanna and F. A. Gifford, Jr., "Urban Air Pollution Modelling," Presented at 1970 International Air Pollution Conference of the International Union of Air Pollution Prevention Associations, ATDL Contribution No. 37.

as a proportioning factor. In this manner the many vehicular sources moving within an individual grid can be represented by a single stationary source, which produces the same amount of emissions equal to the size of the individual grid. This equivalent source is called an area source because the emissions from the grid or area source are now considered as evenly distributed or evenly produced over the entire area of the individual grid.

Step 2. Use of vehicle emission factors to calculate emissions on a per-grid basis.

1. Specific Approach

From urban transportation demand models (the traffic assignment portions), VMT and speed data were obtained. Wherever possible, VMT and speed data were obtained by zone. If no zonal information was available, zonal estimates were made. However, the emission levels are actually used as average zonal values and are rough approximations rather than point measures. In addition, the factors used to convert VMT and speed data into emission levels themselves introduced errors which are of at least equal magnitude to those introduced by allocation of link VMT into zones. Most of the VMT and speed information supplied was for a 24-hour average weekday (in some cases peak-hour data were available) and, therefore, had to be adjusted to estimate the eight-hour and one-hour maximum requirements of the project. These estimates were made utilizing daily hourly traffic counts made available by the traffic departments and transportation planning agencies in each of the cities.

Most of the traffic assignment data provided had base years in 1968 and 1969. These same models generally provided projected values for VMT (and very often speeds) for the year 1980 and beyond. Interpolations, therefore, had to be made for the year 1977. In making these interpolations employment, residential, and population data were used whenever available. When these data or growth models were not available, interpolations were generally based on straight line assumptions.

In a number of cities speed information had to be estimated for each of the zones. When this was done, the speeds were based upon link-node data using weighted averages weighting the respective speeds using link volumes as weights. The program input and output are oriented to a rectangular grid network which overlays the city of interest. The results are presented in tabular form as the average concentrations for each element of the grid network. Punched card output was used to produce concentration isopleths or concentration density maps which were overlaid on a map of the metropolitan area to give a visual representation of the spatial distribution of the pollutant of interest.

2. Program Input

Three groups of input data are required: traffic data, meteorological data, and emission factors for each pollutant.

Traffic Flow Data. The resulting grid network of VMT and speed from above provide the basic traffic flow data required for emission calculations.

To correspond with the time periods specified by the National Ambient Air Quality Standards, peak 1-hour and peak 8-hour VMT are required. For comparison with the ambient air quality standards for hydrocarbons and nitrogen dioxide, a Larsen transformation was used to convert estimates to 3-hour and annual averages, respectively. When these data were not available, they were estimated as percentages of the 24-hour VMT by using traffic count information at various stations within the area. The program applied this percentage whenever necessary to obtain the appropriate data format. Particular streets may vary significantly from the mean values obtained by this procedure; however, the allocation of VMT to grids as described above tends to minimize the effect of individual streets on the predicted concentrations values for the individual grid.

Traffic speed data on a per-grid basis are required as an adjustment to the average vehicle emission factors. Carbon monoxide and hydrocarbon emissions decrease with increasing average vehicle speed; therefore, the emission factors must be adjusted to be more realistic. EPA has published emission factors curves as a function of average vehicle speed for carbon monoxide and hydrocarbons. These curves are incorporated in the program.

The modal split of VMT must be considered, i.e., what is the proportion of cars, buses, and trucks comprising the total VMT. Data on the modal split are not typically available on a detailed basis; therefore, this factor is most readily accounted for in the formulation of area emission factors as discussed below.

Emission Factors. EPA has developed a computer program to produce emission factors for the entire vehicle population for a given metropolitan area for any calendar year from 1960 to 1990 for which vehicle age-type distribution data are available. Emission factors are subject to revision as required by changes in vehicles, control devices, "representative" driving cycles, and measurement techniques.

3. Outputs

1. Annual emissions (tons/year) for each grid and total emissions for a grid network.
2. Emission rates ($mg/m^2/sec$) for each grid.
3. Total 8-hour and 1-hour emissions for each grid.

4. Resolutions

Generally, the data available for each city did not permit classification into fine-grained geographic areas (e.g., the eight rings used for Washington, D.C.). Since the impact of flow controls was based on general experience and judgment, for the purposes of project analysis, the respective cities (except Washington, D.C.) were divided into three broad geographic areas: (1) the CBD or core, (2) an area surrounding the core but still within the political boundaries of the city, and (3) the remaining area outside the boundaries of the city. This three-way division allowed relatively easy division of zones while still permitting our analysis to be somewhat more fine grained than would otherwise be possible.

EMISSION MODELS CHECKLIST

Input Data Requirements

	Within Program	User Supplies	From AP-42	Proxies/Comments
Vehicle Emission Factors				
-By model year	x	x		Uses vehicle mix for year of interest in study
-By size class	x	x		
-By power plant	x	x		
-Deterioration factor	x	x		
Vehicle Operating Modes				
-Hot/cold start		NP		
-Route average		x		Speed and distance
-Link average		NP		
-Mode-by-mode		NP	NP	
Traffic Features				
-Vehicle mix		NP		
-Engine operating time		NP	NP	
-Vehicle miles traveled		x	NP	
-Fuel consumed		NP	NP	
Spatial Distribution				
-Links		NP	NP	
-Grinds		x	NP	
-Area		x	NP	

NP = No provision

Output Available

Pollutants	
-CO	Yes
-HC	Yes
-NO_x	Yes
-Particulates	No

Availability of Program Documentation

	Yes	No
Included in report		x
Referenced in report	x*	
Language	NP	
Equipment	NP	

Valiuation/calibration: Compared with Washington, D.C., camp data; CO CO data show best agreement

Time resolution: 1 hour; 8 hour

Spatial resolution: 1 mile or 1 kilometer square

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* Uses EPA computer program for emission factors for entire vehicle population for a given metropolitan area for years 1960 to 1990.

XXVI UNIVERSITY OF ALASKA

Ice Fog: Low Temperature Air Pollution. Prepared by Carl S. Benson, Geophysical Institute, University of Alaska, UAG R-173, November, 1965.

A. Author's Abstract

Stable pressure systems over interior Alaska sometimes produce prolonged extreme (below -40° C) cold spells at the surface. The rate of radiative cooling of the air is enhanced by suspended ice crystals, which are themselves a result of the initial cooling.

Radiation fogs formed during the onset of cold spells are generally of short duration because the air soon becomes desiccated. These fogs consist of supercooled water droplets until the air temperature goes below the "spontaneous freezing point" for water droplets (about -40° C); the fog then becomes an ice crystal fog, or simply "ice fog." During the cooling cycle, water is gradually condensed out of the air until the droplets freeze. At this point there is a sharp, discontinuous decrease in the saturation vapor pressure of the air because it must be reckoned over ice rather than over water. The polluted air over Fairbanks allows droplets to begin freezing at the relatively high temperature of -35° C. Between -35 and -40° C the amount of water vapor condensed by freezing of supercooled water droplets is three to five times greater than the amount condensed by 1° C of cooling at these temperatures. This results in rapid and widespread formation of ice fog, which persists in the Fairbanks area as long as the cold spell lasts. The persistence of Fairbanks ice fog depends on a continual source of moisture (4.1×10^6 Kg H_2O per day) from human activities within the fog.

Ice fog crystals are an order of magnitude smaller than diamond dust, or cirrus cloud crystals, which in turn are an order of magnitude smaller than common snow crystals (0.01, 0.1 and 1 to 5 mm respectively). The differences in size are shown to result from differences in cooling rates over five orders of magnitude. Most of the ice fog crystals have settling rates which are slower than the upward velocity of air over the city center. The upward air movement is caused by convection cells driven by the 6°C heat island over Fairbanks. This causes a reduced precipitation rate, which permits the density of ice fog in the city center to be three times greater than that in the outlying areas.

The inversions that occur over Fairbanks during cold spells begin at ground level and are among the strongest and most persistent in the world. They are three times stronger than those in the inversion layer over Los Angeles. Thus, the low-lying air over Fairbanks stagnates and becomes effectively decoupled from the atmosphere above, permitting high concentrations of all pollutants. The combustion of fuel oil, gasoline, and coal provides daily inputs of 4.1×10^6 kg CO_2; 8.6×10^3 kg SO_2; and 60, 46 and 20 kg of Pb, Br and Cl respectively, into a lens-like layer of air resting on the surface with a total volume less than 3×10^9 m^3. The air pollution over Fairbanks during cold spells couldn't be worse, because the mechanisms for cleaning the air are virtually eliminated while all activities that pollute the air are increased.

B. Summary

Aqueous emissions are an important pollutant in Fairbanks, Alaska, in cold weather, when the capability of the air to hold water in solution is reduced. The Geophysical Institute, University of Alaska, estimates aqueous and CO_2 emissions from combustion, power plant cooling ponds, and miscellaneous sources, such as sewage treatment plants, mine tunnels, people and animals breathing.

1. Combustion Emissions

Complete combustion of the representative molecular species is assumed, with average molecular weight ratios of 1.38 (H_2O/fuel) and 3.10 (CO_2/fuel) for gasoline and 1.33 (H_2O/fuel) and 3.13 (CO_2/fuel) for fuel oil. For coal, the calculation of these ratios is more complex because the water contained in coal is exhausted directly to the atmosphere during combustion. It is assumed that 20 percent by weight of the coal is water. Total molecular weight ratios for coal are 0.68 (H_2O/fuel) and 2.37 (CO_2/fuel).

The above ratios are applied to the quantities of each fuel type burned to give monthly and daily emissions of H_2O and CO_2.

2. Power Plant Cooling Emissions

Given the water flow rate to and from the cooling pond and the net temperature change of water, the required heat loss may be calculated. This heat loss is accomplished by three processes: (1) evaporation to the atmosphere; (2) radiation to the sky; and (3) conduction through the bottom of the pond.

Assuming an extreme winter vertical temperature gradient in the pond, no convection in the water, and the condition of all heat conducted downward being conducted away through the soil below, the calculated vertical heat flux from conduction for a large plant at Fort Wainwright, Alaska, is less than 0.1 percent of the total required flux. Therefore, conduction can be neglected.

Radiative cooling is maximized using

$$Q = 0.105 + 0.0018\ T$$

and multiplying Q by the area of the pond. A temperature T over the open water surface must be assumed. The value of maximum radiative heat flux at the plant cited above is slightly over 5 percent of the total flux and is negligible when ice fog forms over the pond. Therefore, during ice fog conditions, the evaporative heat loss approaches the value of the total heat loss.

To estimate the amount of water introduced into the atmosphere from power plant cooling waters, each plant must be analyzed separately in a manner similar to that described for the Fort Wainwright plant.

3. Miscellaneous Emissions

Aqueous emissions from miscellaneous sources such as sewage treatment plants are treated individually by calculating heat loss from the warm water discharge flow rate, the amount of open water area, the amount of heat dissipated by mixing with river water, and so forth. For tunnels, the moisture flow rate through the fans (and therefore the emission rate from tunnels) are estimated using the air flow rate past the fans and the relative humidity and temperature of the air. Another important source of aqueous emissions in very cold climates is the breathing of people and animals. Saturated air is exhaled at 35°C. This exhalation process together with respiration rates and the populations of each sex and species gives the amount of water vapor released to the environment. It has been shown that the loss of water vapor through perspiration exceeds the loss from respiration; therefore, the moisture output from breathing can be doubled to give a combined perspiration and respiration loss.

Other miscellaneous sources include moist air discharge from laundries and air leaks from buildings and houses.

XXVII UNIVERSITY OF CALIFORNIA AT DAVIS

The Impact of Highways on Air Quality. L. O. Myrup, unpublished report, August, 1972.

A. Author's Abstract

None Given.

B. Summary

Carbon monoxide emissions for Sacramento, California, input to the pollution transport and diffusion model developed at the University of California at Davis are distributed into 1.7 mi^2 areas. Total emissions for each area are formulated by first measuring the total miles of residential streets, arteries, and highways in each area. The average traffic volumes for each of the three types of streets are obtained, and car-mile factors computed. Vehicle emission factors at appropriate vehicle speeds are then applied, yielding the total amount of pollutant for each kind of street, and after summation, the total emissions for the grid square in question.

C. Model Availability

No computer program for the emission inventory methodology presented is available.

XXVIII U.S. WEATHER BUREAU

A Simple Diffusion Model for Calculating Point Concentrations from Multiple Sources. J. F. Clarke, Journal of the Air Pollution Control Association, September, 1964.

A. Author's Abstract

None given.

B. Summary

The application of a method designed by Hagan, et al. (1964)[1] resulted in the source inventory for the city of Cincinnati used in Clarke's calculations. Two source categories for sulfur dioxide and nitrogen oxides are presumed: (1) combustion sources, which include space and process heating, power generation, transportation, and waste incineration sources; and (2) industrial process losses, which include only the losses from processes, not from combustion. Emissions are allocated on the basis of unit-area emission rates for each of 19 areas suggested by population density maps and modified subjectively to more clearly define commercial and industrial areas.

Among the assumptions made in apportioning emissions are that the amount of fuel used for space heating is directly proportional to the degree day value, and that this fuel is used only during days registering a degree day value. It is assumed that industrial and commercial sources that use fuel for power and waste incineration and process heat operate at a uniform daily rate. Fuel used for transportation is taken as constant for days without a degree day value and inversely proportional

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[1] J. E. Hagan, III and G. A. Jutze, "A Rapid Technique for an Air Pollution Emissions Survey," Public Health Service Manuscript (1964).

to that value when one is registered. This assumption is based on seasonal variations of gasoline sales.

The industrial process losses used are engineering estimates derived from knowledge of the characteristics of the individual processes, as sufficient quantitative data was not available.

One power plant was thought significant enough to be included as a point source. The plant does not operate at a uniform daily rate, and fuel usage is not a simple function of season or time of day, since the output of the plant is used to both heat and cool, according to season. Since operational data from the plant were not readily available and the precision of the general inventory did not seem to warrant the effort required to calculate otherwise, emissions from this plant were taken as invariant in time.

C. Model Availability

A computer code for the emissions treatment used for Cincinnati is not referenced in the paper.

Validation of Area and Line Emission Models

Validation of area and line source emission models will be undertaken. Although the methodology has not yet been investigated, the approach will probably include selection of certain specific line source segments or area source grids (or airports or railyards), placement of air pollution monitoring instrumentation upwind and downwind of the source from ground level to some specific altitude, and determination of pollutant concentration flux across the source, thereby ascertaining the amount emitted from the source and verifying the source inventory/emission factor/emission model system which calculated the estimated emissions during the validation period.

RAPS Emission Inventory Data Handling System

The RAPS emission inventory data handling system was designed to NADB specifications by Rockwell International, Science Center (1) using the Stanford Research Institute report (2) as a starting point. The system will be implemented initially by NADB, with the RAPS data manager operating it following start-up.

In advance of the computerized system, NADB provided existing emission inventory and associated data to the RAPS data manager. Initial edit-storage-analysis-retrieval programming will become available in late FY 75. Additional work will take place in following fiscal years. All programs will be documented using NADB procedures and duplicate copies of the documentation will be kept by the RAPS data manager.

All requests for data by users must be directed to the RAPS data manager. Any additional programs developed by RAPS users or their contractors accessing the emission inventory data must be completely documented and supplied to the data manager and NADB. No changes in any existing programs should be made without prior discussion with NADB.

1. RAPS Preliminary Emission Inventory, Stanford Research Institute, PB 232-223/AS, January 1974.

2. RAPS Emission Inventory Data Handling System, Rockwell International - Science Center, Contract No. 68-02-1081, Task 20.

HARDWARE SYSTEM

EMISSION INVENTORY FILE SYSTEM

A. General

This section concerns the specifications for data formats in the emission inventory. Because this inventory is intended primarily for air quality modeling in the RAPS program, the data elements were chosen to provide input data and supplementary documentation for that purpose.

The data structures specified below are extensible data items in a data reference system that provides the facilities to manage such data types. Data systems of this kind have been developed and are available. We describe in this report the main functional features of the inventory system, and the computer system interfaces needed to provide data to modeling programs.

Although most of the expected categories of data are used to demonstrate the data structures and formats, this chapter is not intended to be a complete listing of the content of the emission inventory. Because the data structures are specified to be extensible, any data not explicitly shown can be attached to the structure.

Section B describes the computer system environment in which we are assuming this inventory will be implemented. Section C discusses the main operational aspects of the inventory. Both of these discussions provide the basis for the design of the data structures described in detail in Section D. Section E suggests a possible alternative format for implementing these data structures in the absence of a supporting data reference system. Section F lists the steps required for implementation of the inventory system, and Section G is a tabulation of the principal specifications of the computer programs needed.

B. System Environment

In this section, we discuss the key features of the system and software environment in which the emission inventory will be implemented. A data management system will be needed for the operation of the RAPS Emission Inventory, although it may be possible to perform the inventory operations with systems not having exactly the features described here. Data management software is usually the responsibility of the central computing group of an organization, however, because this system must meet the needs of the Air Data Branch for the inventory functions, specifications for the system are given in this report.

Either a general-purpose or a custom-designed data management software system must be obtained or constructed that will run on the computer facility at EPA-Durham. This data management system should provide the basic functions of file definition; addition, revision, and deletion of data items; retrieval of selected items using selection criteria on data content; hierarchic sorting by content; and output of specified data components of selected items in specified formats to construct files for use in other programs.

The system should provide for defining hierarchically structured data items, with components consisting either of single data records or lists of records, subordinate to other components of the data item. We assume that the system will provide means for assigning names to each of the components of a data item. The system should provide functional records of any desired length to contain character strings.

The system should provide for data entry from punch cards, tapes, and terminals (if it functions in an on-line or interactive mode). It should also provide for merging of preliminary files from disk. Data should be readable as ASCII character strings. Conversion of declared numeric data to numeric internal representation may be provided, but is not necessary. The system should not pad card input with blanks and should provide for continuation of a data record to successive cards until the record is terminated by an end-of-record character.

For the purpose of this emission inventory, all operations can be carried out in batch operating mode. However, Dr. Ruff has indicated that the RAPS program will have other data base requirements, and that compatibility among these different data bases would be operationally and economically beneficial. One level of compatibility that can be obtained is to use the same data management software to implement all of the RAPS data bases. Some of the data base applications may require on-line use of the data system for retrieval and perhaps even for data entry. Therefore, it would be desirable for the data management system to have the potential capability of being used in an on-line mode, perhaps by means of additional software options.

All of the presently existing air quality models are written in Fortran. The primary purpose of the emission inventory file is to provide input data to these models. Therefore, a system that has an interface for Fortran programs would be advantageous, because the input data files could be constructed by means of Fortran programs that could access the inventory files through the system interface and write data in the formats and data representations required by the models. Since the inventory file formats include data embedded in character strings, using various separator and operator characters, these records must be decomposed by the Fortran interface programs, the numerical values extracted as character strings, and converted by the interface into proper internal number representation for arithmetic operations. This translation of the internal formats will have to be added to any interface routines that a data management system may already have.

Dr. Ruff has stated that EPA-Durham will obtain the Univac DMS-1100 data management system when their Univac 1100 computer is installed. DMS-1100 is described in a catalog as a host language system: it is based on Cobol and can be utilized only by Cobol programs that issue calls to the data management system for file operations. DMS-1100 is not in itself a complete data management system. It must be implemented by writing Cobol programs to perform the functions of defining and labeling data structures, entering data, sorting and indexing, and formatting output data. There is no Fortran interface to DMS-1100, so additional system programming work would be needed to provide a facility for generating input files to models if the inventory is based on DMS-1100.

At this time we do not have sufficiently detailed information about the facilities and file structures provided by DMS-1100 to be able to make any positive recommendation concerning its applicability to the RAPS Emission Inventory.

It is estimated in Section IV on Task B that the total number of point sources that should be included in the RAPS inventory will probably not exceed 1000. The number of area sources will depend on how the areas are defined. If each area is only 1 square kilometer, then there may be several thousand area sources to be described. However, the format described here allows for any size and shape of area source and also for including sets of equivalent area sources in one item, so the number of inventory items needed to describe the area sources can be reduced to a few hundred if this feature is used. The line sources that need to be described will be mostly major traffic routes, and they should be relatively few in number.

For the purpose of specifying the capacity requirements of a data management system for the RAPS inventory, we can probably put an upper bound of about 2000 data items per file. For some point sources, the data elements may be fairly detailed, but most source items will describe only one or two products or pollutants, and only a few typical patterns of time dependence can be predicted by emission models, so that most of the data items will contain from 200 to 500 characters for a total of about one million characters. The longest elements in the file will be the hourly data on consumption and emission for about 50 point sources, each of which will require up to 75,000 characters to describe hourly consumption to 1% precision for a year. Then, if hourly emission values are also stored for an average of three pollutants for each such source, the total size of each of these point source items will be about 300,000 characters, or 15 million characters for 50 sources.

The master inventory files will be easily accomodated on a single large disk pack, such as the IBM 3330, or the Univac Fastrand drum, which holds over 100 million characters per drum. Therefore, the storage of emission values in the inventory file will not significantly affect the computer facility requirements.

The accumulation of historical inventory data, over a period of years, will most conveniently be accomplished by making a separate file for each calendar year with the possible exception of the first one, which will have to average several prior years experience. If this system is eventually extended to maintain emission inventories for other regions, each Air Quality Control Region (AQCR) should be handled as a separate set of data files.

C. Inventory Operations

To define the data formats for a system file, it is necessary to have a view of how the file will be used as a part of an overall system operation. In the case of this emission inventory, there are three major operational activities: source data preparation and entry, computation of emission values of sources and production of data file inputs to air quality model programs.

A principle we have followed in designing these data formats is that source data should be organized and filed with a minimum of manual transformations from the form in which it is gathered to the form in which it is entered into the computer. Thus we have chosen to organize the file with sources as the primary items, and we are making provision for entering the names of fuels, pollutants, and other materials in readable standard nomenclature. Consumption data should be entered in the units in which it is normally described to avoid manual computations and errors. The emission modelling programs can compute emission values in standard system units.

The SAROAD parameter coding manual of EPA has assigned integer code numbers to many hundreds of compounds of interest in air pollution. However, only a relatively few pollutants will be included in the high resolution emission inventory for air quality model verification. Furthermore, the SAROAD codes do not include materials other than air pollutants, such as consumables that will be included in the emission inventory as a basis for computing emissions. Finally, writing 'SO2' instead of '42401' to describe sulfur dioxide is more brief, more readable, requires no catalog look-up by an inspector or data clerk, and is far less error prone.

We suggest, in this report, that compounds and other materials be labeled mnemonically and concisely. Of course, it is essential that the labels be absolutely consistent. Since the number of materials is expected to be relatively small, a standard thesaurus of material identifiers should be easily maintained.

A considerable amount of data is needed to identify and describe each source in addition to the set of values for emission or consumption of a variety of possible pollutants or materials and a specification of the time dependence of those values. The number of different kinds of sources and different materials indicates that a hierarchic list type of data structure is most applicable to this purpose.

In connection with model sensitivity studies or studies of control strategies, it will be desirable to be able to include the effects of simulated sources, or real sources operating under simulated conditions or under actual but very unusual conditions. All such sources can be entered into the Master Inventory in the standard way, but identified by an appropriate category name so that they can be selectively included with or substituted for real sources in data files for model runs.

It is expected that most of the data will be entered in a batch mode via punched cards or using key-to-tape machines. In either case, the hierarchic structure of the data items must be represented in the character stream by additional delimiter characters. An extended format for this purpose is described in Section E on extensions for batch data entry; however, any existing system will have its own format for batch entry. This format is sufficiently complicated that it is recommended that the data be written by a skilled data clerk, who can transcribe original data from an inspector's notes or from data collection forms. This clerk should also be qualified to proof read data entries both for syntactic correctness and for data sense. Data preparation forms can be used to aid in the structuring of the data and to make it easier to use the correct syntax and punctuation characters. However, it is not possible to depend only on well-designed data preparation forms for data quality, because the content as well as the form of the data must be verified.

A data management system generally will check its own data entry syntax, and should be used for this purpose. However, the internal formats of some of the data elements, such as consumption data, will be transparent to the system and will need to be tested by a separate emission inventory verification program. The same program should also verify whether material names are included in the material name thesaurus. This thesaurus therefore should be kept in the form of a computer reference file available to the data entry program as well as in paper reference copies in the data preparation rooms. For example, the substitution of the digit-'0' for the letter-'O' in SO2 by a typist can be detected this way. The same kind of verification should be applied to all other data descriptors for which there is only a small number of correct choices. The verification program should make output listings of all items in which it detects errors in a form in which the erroneous data component or syntax is identified. Although the verification program could include facilities for user-entered corrections, it will be more practical to use the editing facilities of the data management system for this purpose, and this is recommended as the preferred approach.

Data should be entered first into a preliminary data system file, so that they can more easily be further verified by printing out the entire content of a small data set in an expanded easily readable format for proof reading and further correction prior to adding these items to the main inventory file. Another reason for this preliminary stage is that most data management systems perform a significant amount of behind-the-scenes processing on new entries into a directly accessible file, such as building address tables, hash coding computations, making inverted lists of key data elements. The small preliminary file, on the other hand, can be a simple sequential file with none of this extra processing until after the data manager has determined that it is accurate enough to merge it into the main file.

The retrieval facility of the data management system will be used for the selection of groups of sources for which emission values can be computed by the same model or are selected for production of a particular data file for model validation or for editing and updating of selected items. The retrieval of source items should be accomplished on the basis of any appropriate data in the item, such as source category, pollutant, location, or status of previous computation of emissions.

The retrieval facility can also be used to produce special files organized in terms of any user-specified parameters, such as a pollutant, sources using fuel at greater than some rate, location. This can provide for a variety of special applications without requiring additional file programming. A sorting capability in the data management system should be provided to order and index these files by their content.

In very few cases will source data include measured values of emission. For most actual sources, the emission must be calculated from consumption or other source data. Formats are provided in this inventory for both emission data and consumption data, using the same data syntax and structure for both. For those sources for which there are no direct emission data, emission must be calculated using emission factors or emission models applied to consumption or activity data. The emission factors have been compiled by EPA into a table as a function of the Source Classification Codes (SCC) for a wide variety of industrial processes and consumables.

After a set of new data source items has been entered, the next logical operation is to calculate the emission values for those sources that have no pollutant data entered. The results of these computations can be appended to each source item as the content of a pollutant component using the same time interval description for each source as was used for consumption if only the emission factor is applied. If a specific emission model is used, the time interval description also must be generated by the model program.

The emission inventory software system will require emission model programs that can access the consumption data element for each item, refer to the SCC code for that material, look up the appropriate emission factor in an auxiliary Emission Factor File maintained as a direct access file on the system, and compute the emission values for each of a prespecified set of pollutants. If the programs have access to the data system for file writing as well as reading, they can then update each item by adding a pollutant list component with an entry for each pollutant to be calculated. One of these will be a "no model" program that will only multiply consumption data by emission factors to obtain emission values. These emission models will generally also require input of ambient atmospheric data, which can be obtained from meteorological data files based on the RAPS data network. These files are not considered in this report, because they are not part of the Emission Inventory system.

In this manner, the master emission inventory file will serve both as a file of input source data and also as the repository for derived emission values with no duplication of source information.

For the principal objective of the RAPS program the final function is that of production of input data files for air quality models. In general, the required emission data will be that for a specified pollutant for a specified time interval or series of time intervals and also for specified positional coordinates. Many data management systems have search and retrieval features for selecting data items that satisfy specified data constraints or specifications. Some preliminary selections may be made using the system facilities, such as selection of a particular type of source, certain UTM coordinate ranges, and the like. However, the time dependence data are coded in the emission data element format in a special way, and a general system feature will not be able to decode it.

If the general data management system includes the capability for calling procedural language subroutines, such a subroutine can be written to decode the time and emission data in the emission data element and can be linked to the data system so that it will automatically be invoked whenever the system is asked to search for emission data within some particular time range. If that capability is not available, then the data file production program must have a subroutine included within it to perform the time interval selection function.

After the items containing the desired data have been identified, it is necessary to abstract the emission data for the particular pollutant and write an input data file for the model program. The input file must be written in exactly the format expected by the model; the values must be in the units defined for that model program. Since the model programs are written in Fortran, the data file must also be written with the appropriate integer or floating point representation for each quantity.

The generation of these input data files will require interface programs designed to perform this task. These programs (or maybe one general-purpose file-building program) must read the emission data elements that are character-string data, decode them, compute new time sequences if the model requires them, transform the string representation of the emission value to internal numeric form, read the name of the unit used and multiply the values by the proper conversion factor, and write the file for the model.

Most of the air quality models operate on the basis of allocation of emission values to a fixed geographical grid system. The data interface programs will also have the function of translating the geographical coordinates of point, area, and line sources in the inventory into the appropriate grid units for the model.

The data file derived from the RAPS Emission Inventory can be combined with similar data files derived from other source inventories, such as NEDS, to obtain the most economical use of existing systems. It is assumed that programs to generate input data files for atmospheric models already exist in the NEDS system. If such programs do not exist, then it may be more economical to transfer all the NEDS data relating to the RAPS area into this RAPS inventory system.

The only sources that may be duplicated in both systems should be those for which time-resolved data can be obtained. Since there are expected to be not more than one or two hundred such sources, it will not be efficient to provide a program for computer translation of NEDS to RAPS data. It will be cheaper to manually copy these source data, especially since much of the data for each source will be new. If, eventually, the use of the RAPS inventory is extended to cover much more data from other areas, then the possibility of computer transfer of data between the two systems should be re-examined.

Figure 3 shows a schematic of the inventory system.

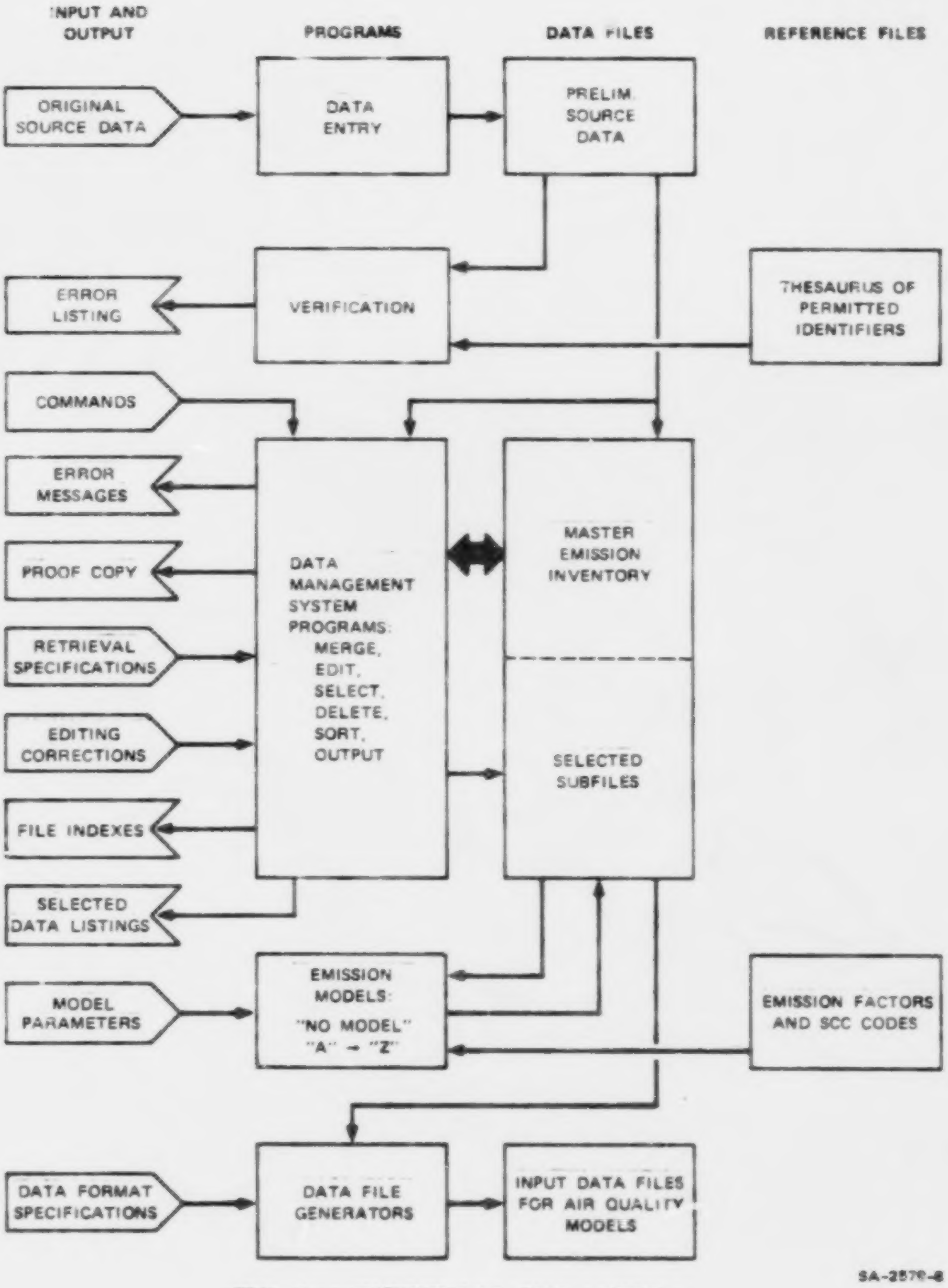

FIGURE 3 SCHEMATIC OF INVENTORY SYSTEM

D. Data Structures and Formats

1. Source Categories

The three principal categories of emission sources are point, line, and area. Because they require sufficiently different identification parameters, they should be filed by using different item data structures. They can be stored in separate computer files or in the same file in different item categories.

Point sources can be identified by the use of a group of identification parameters selected from those given in the manual for the NEDS inventory. Although this is a RAPS emission inventory, some of the NEDS identifiers are included primarily to facilitate data interchange between the two systems. The primary identifiers should be:

* Assigned source item number (sequence number assigned by inventory system);
* Source category (e.g., power station, foundry, refinery);
* Source name (name of company, organization, or generic name if it has no specific name);
* Plant No., Point No.;
* Street address (or nearest street identification);
* City, County, State, AQCR No.

The UTM coordinates are not included in the source identifiers of point sources, because each stack of a multistack source will have its UTM coordinate position in the data item. If some stacks at a plant have different emission values or time sequences than others, more than one data item will be needed to inventory that plant. The Point No. is intended to identify such different sources within a plant.

The NEDS Source Category Code (SCC) is included as part of the identification of each consumed or manufactured product, rather than as a single-valued source identifier, because a source may utilize more than one product. The code includes both the material and process identification.

Location, source category, and sequence number identify area sources. Predetermined area sizes or shapes need not be allocated. Any closed simple area bounded by straight lines can be uniquely specified by the coordinates of the intersections of these lines taken in order. Thus the areas can be selected on the basis of convenience and appropriate internal contents without size or shape restrictions. Area sources can overlap; for example, an area identified for automotive emissions may include or overlap an apartment house area. The recommended identifiers for area sources are:

* Item number;
* Source category (e.g., automobiles, residential, dump);
* Area number (assigned sequence number);
* List of UTM coordinates of corners of boundary (starting with most westerly or southwest corner and going clockwise);
* City, County, State, AQCR No.;

- English language paragraph for general descriptive purposes. This should always include a street or locality description to supplement the UTM coordinate specification.

Identification of line sources will be similar to that for area sources except for the significance of the UTM coordinate list. The sequence of the UTM coordinates of the end points of a connected sequence of straight lines approximating the position of the source will locate each line source.

2. Data Item Formats

The items of the file will consist of point sources, area sources, or line sources.

Many sources will have fuel-burning data or process rate data instead of direct emission data. For some plants, the materials being produced may be significant sources of air pollutants, and these products can be included in the process category. Or, if data are lacking on either, an activity may have to be identified to which an average emission model can be applied (for example, automobile traffic). An activity might be included for some point sources (like a freight terminal), if the fuel or emission rates cannot be measured directly. Thus, three different components of the source data that can be used in combination for some sources are:

- Emission data
- Consumption and process data
- Activities.

In the case of consumables, the data element would describe rates of consumption. For activities, the possibilities are so varied that no single standard format for descriptive data is likely to be usable. One example of an activity, automobile traffic, is discussed in the line source category.

Except where direct emission data are available for a source, the emission can be calculated from the consumption or activity data by application of emission factors and emission models, and the result entered into that source item in the inventory file as calculated emission data.

a. Point Sources

Any point source may emit one or more of several pollutants of interest. If data capacity is provided in each item for all possible pollutants, the file structure will be inefficiently used (mostly empty). A more appropriate structure would use list elements implemented such that each pollutant or consumable actually included in the item list is associated with a pointer to an associated data element, each of which is a logical record of variable length. This will permit efficient use of computer storage and efficient retrieval and selection of data for construction of model input files.

In some data reference systems, the system automatically maintains the pointers on the basis of the data linkages specified during data entry. If the system does not provide internal pointers to associated data elements, then explicit addresses (such as record number) must be written in the file, and the user must maintain the necessary address directory.

Figure 4 illustrates a sample point source item.

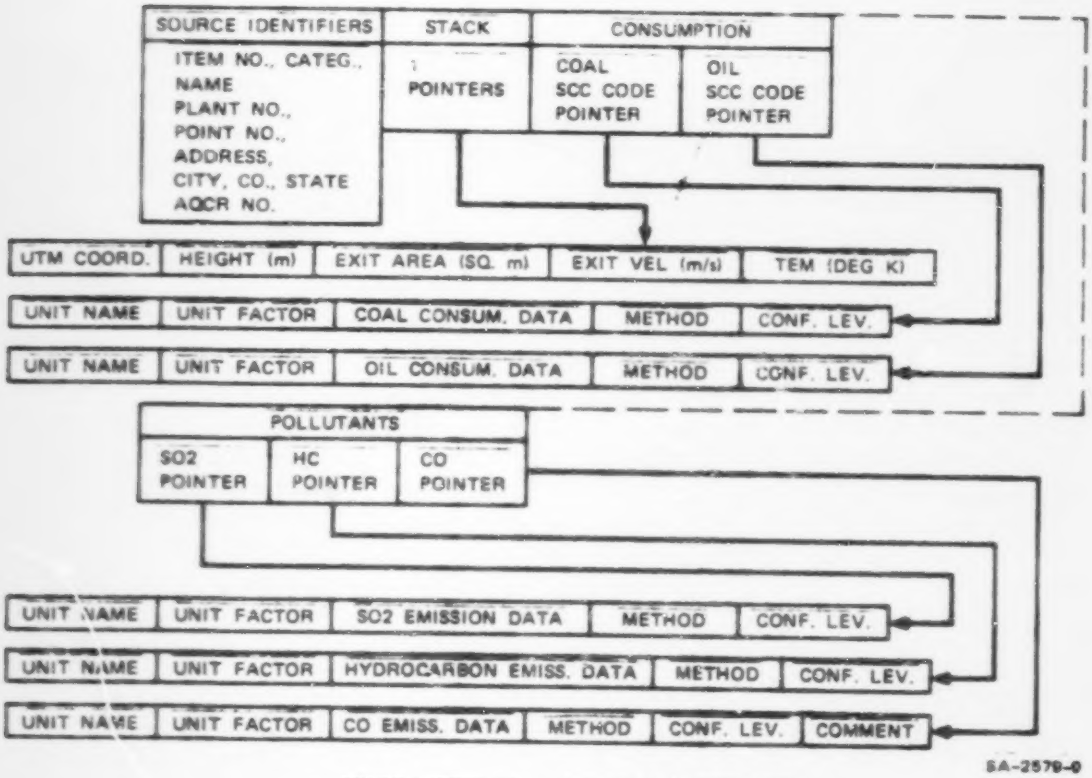

FIGURE 4 SAMPLE POINT SOURCE ITEM

The Stack component can describe any number of stacks at one point source. The element will contain the number of stacks, and a pointer to a data element for each stack containing a standard sequence of parameters: UTM coordinates, height(meters); exit area(square meters); exit velocity(meters/second); gas temperature(deg K).

If each of the second level data elements, as shown in the example, consists of a fixed sequence of data components, with only the last one (comments) optional, then the separate components do not require system identifiers.

b. Area Sources

Because the format of an area or a line source will have to provide for an indefinite number of UTM coordinates, these are placed in a separate data element. The area and line sources are defined in terms of a single principal pollutant; thus only that pollutant is identified, instead of a list of them as in a point source item. The emission of that pollutant will usually have to be computed from consumption data by means of standard emission factors, so the consumption data should also be included in each area source description in the inventory.

Figure 5 shows a sample area source item.

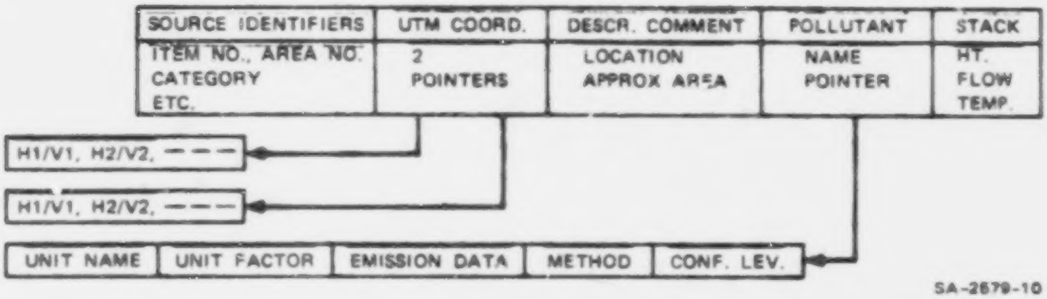

FIGURE 5 SAMPLE AREA SOURCE ITEM

This example shows how two separate areas can be included in one area source item. An area source item can describe a set of non-contiguous areas to avoid duplication of the complete description of each of a set of area sources having identical emission characteristics. The number in the UTM Coordinate component specifies the number of different areas described in the item. For each area, there will be a separate data element containing its coordinates.

The Stack data in an area source item refers to an equivalent stack for purposes of dispersion modeling. The stack area is assumed to be the whole source area; volumetric flow rate is estimated from fuel or other consumption data. The consumption data component is not shown in this sample; it is structured the same as the consumption component shown in the point source sample.

Only a very slight change in format is needed to use a single area source item to describe the emission of more than one pollutant, as in point sources. Therefore, although we are here suggesting a single pollutant per area source item, that choice can be made by the emission inventory manager at the time that the areas are defined.

c. Line Sources

An important type of line source is automobile traffic. The format of line source items will differ from area sources primarily in the significance of the UTM coordinate list that will be the endpoints of straight-line segments approximating the road route. The category name "Road" can identify this type of source. The activity name can be "Automobile", and additional elements should be appended to the item under the names:

- Traffic (average vehicle flow, average speed, vehicle mix)
- Way (type, dimensions).

3. Other Data

File data describing the composition of fuels or other consumed materials may be useful in the inventory, if they are variable for different sources. A data element for composition can be attached to any entry in the consumption list by a second pointer. The pointer identification is: Pointer 1 to the consumption data element, Pointer 2 to the composition data element (if any).

The composition element can be a paired list of impurity element symbol or compound formula and weight fraction for as many constituents as are signifacant. The element or formula name can be terminated by a blank, and each pair can be separated by a slash. A sample is shown below.

S .02 / As .005

Another category of data that may be needed in some source items is certain special emission factors, such as those for nitrogen oxides, for sources where there are actual measurements of the factors. The measured emission factors can be added to the data structure by a third pointer under the appropriate consumable. The emission factor data element will have to identify each pollutant calculated by each factor. The data can be entered in the same format as that for composition, above, except that the identifiers will be pollutants and the numerical values will be emission factors.

Other source data may be added to any item by use of a labeled pointer to an extension record. Any number of such extension records may be attached to any item, but no additional storage space need be allocated to items that do not include such data.

4. Data Element Formats

Most of the data elements will be numeric or text constants and will require very little formal formatting. Real numbers must be written in standard notations such as decimal or exponential (ie. 94.27, 1.03 E-4). Text elements can be written free-form. It is often convenient to have one printing character such as "#" or "$" defined as a text element terminator. A continuation character can also be defined to enable the entry of multiline text elements. On some systems, the linefeed key is most effective for this purpose, because it initiates a new line at the terminal.

The emission and consumption data elements, on the other hand, can have a large variation in amount of data and should allow for different levels of time resolution. These therefore require format rules to provide exact identification of descriptors and data.

Since the data elements for consumption data may deal with a large variety of consumable products, a single unit of measure (e.g., grams/second) may not always be appropriate. Therefore, the first component of the data element is the name of the unit of measure and the second is the conversion factor to convert that unit to the standard inventory system unit.

For those sources for which a series of time-sequence measurements are available, it will be useful to describe the emission or consumption by those measurements. On the other hand, there will be many sources, especially area sources, for which only approximate estimates can be made, usually on the basis of some repetitive patterns over time. The format rules described below can be used to describe either a consecutive time sequence or repetitive time patterns or any convenient combinations of both. This component of the data element may be very long (up to 75,000 characters), but it will still be one logical record.

Each emission or consumption data element also includes a component for Method, for Confidence Level, and an optional component for any further comments that may be considered useful to add for documentation of the data. Method will generally be described by means of a concise standard descriptor or abbreviation of the name of the method used to obtain the data. For example, "EF" can identify emission values calculated from consumption data by application of the standard Emission Factor table. Confidence level should be an estimate of the probable error of the values given, based on a knowledge of the errors of the method of measurement, or the reliability of the source data.

The emission element format is the following:

Data Element = Unit name + Unit factor + Data Part + Method +
Conf. Level + Comment(optional)
Data Part = Time Part/Data Part or Value
Time Part = Time Code:Time Range or (Time Part, Time Part, ...)
Time Range = Time Identifier or Time Identifier-Time Identifier
Time Code = A, M, W, D, or H

This definition is hierarchically recursive, so that nested data sets can be constructed by combination. For example,

M:11-2/H: means Monthly groups, Nov. to Feb. range, hourly data. Because there are no time units specified between months and hours, it also means that the hourly pattern repeats daily during that range of months.

Operator characters are:

:	means a 'range/data' sequence follows;
/	means a datum or a data set follows;
,	is a separator between components of a simple data set;
;	is a separator between data sets of a multiple data set;
-	is a connector between first and last time identifiers (inclusive) of a time range;
( )	enclose a multiple group of time pattern descriptions.

Some examples are:

M: 1/1.4,2/1.7,3/1.9,----12/1.3; is a set of values for each of the 12 months.

H: 1/9.7,2/10.3,----24/8.2; is a set of 24 hourly values, for some "average" day.

(M:11-3/D:7-1/H:21-7, M:6-7/D:1/H:22-6)/1.4; specifies a repeating pattern of 8 pm to 7 am on Saturdays and Sundays during November through March, and 9 pm to 6 am on Sundays during June and July, with an emission value of 1.4 units during each of these intervals.

This looks complicated, but the notation is self-descriptive once the user becomes familiar with the meaning of the punctuation symbols. It satisfies two important criteria; it can concisely describe a large variety of possible time-dependent data, and it can be read by machine.

There appears to be no way to design a preprinted, "fill in the blanks", form for data to be entered in this format. The reason is that the format is designed to provide a concise method of describing any sequence or repetitive pattern of time-dependence using several different time units, so that the syntax must be dynamic as in a language, rather than a static syntax that can be preconstructed.

For each time interval code, the total period covered, and the notation is shown in Table 9.

Table 9
Time Interval Codes and Ranges

Time Interval	Code	Period	
Annual	A:	range in calendar years to which the data applies (e.g., 69-73)	
Monthly	M:	1 year	1-12 values
Weekly	W:	1 year	1-53 values
Daily	D:	1 week	1-7 values; 1=SUN, 2=MON, 3=TUE, 4=WED, 5=THU, 6=FRI, 7=SAT
Hourly	H:	1 day	1-24 values

All the time units refer to inclusive intervals (i.e., M:1-2 means January and February). Counted hours, not clock time, is used (i.e., H:7-8 means from 6 am to 8 am). Zero (0) is avoided because it leads to confusion in data entry and because it is not common usage. Since the week is defined to be Sunday through Saturday, a year will generally begin and end with a partial week, so that there will always be 53 identifiable weeks in every year.

The emission data should correspond to the average emission during the specified interval, for a current example of the period. Multi-nested intervals can be used where sufficient data exist and the emission changes considerably over the larger time intervals. For example, hourly emission data for an average day during each of several months may be useful, if the emission rates change considerably through the year.

The large choice of time intervals permits the entry of detailed time-dependence of emission if the information is available and less detailed averages when that is all that is known. If data are available only for portions of a data set, only those elements of the set need be identified and entered in the inventory because the format includes a numeric identifier for every time interval for which data are entered.

Since M: and W: interval sets both cover a period of one year, they are mutually exclusive. The D: and H: intervals can be used with any one of the first two in a multiple set, and D: and H: can also be combined. By the use of these formats, each emission data element can contain as few as one value, averaged over a typical year, or a value for every hour of a year.

Although it uses a concise notation, this format is sufficiently redundant to permit recognition of many entry errors. Manual proofreading will detect many common typing errors, and the use of the computer for checking the internal consistency of data and the syntactic correctness of the data elements will also be feasible.

5. Summary Listing

The following listing summarizes the form and arrangement of identifiers in a source item. Generally, most of the entries will be data relative to higher level identifiers and an identifier for lower level data. They will only be entered into an item if they represent actual information so that only a small fraction of the entries in this table would occur in any single inventory source item. Many of the entries in the table (e.g., names of pollutants) represent only a few examples of an unlimited set of possibilities and are included to display their arrangement and notational style.

```
Point
     Identifiers
          NO.                        Item number.  For file maintenance.
          Category                   Type of source
          Name                       Ordinary name of facility
          Street address
          City, County, State, AQCR No.
     Pollutants
          SO2                        Chemical formula or abbreviated name
               Unit   Emission rate data   Method   C.L.   Comment
          HC
               Unit   Emission rate data   Method   C.L.
          .
          .
          .
     Consumption
          Coal   SCC code
               Unit   Consumption rate data   Method   C.L.
          .
          .
          .
     Activities
          Trucks
               Count/day
          Helicopters
               Count/day   Comment
     Stacks    Count
          UTM coord.   Height   Exit area   Exit velocity   Temp.
          .
          .
          .
Area
     Identifiers
          NO.
          Category
          Area Number                Assigned for map reference
          City, County, State, AQCR No.
          UTM Coord      Area count
               Coord list
          Description of area
     Pollutant      Heat
          Unit   Emission rate data   Method   C.L.
     Consumption    Fuel Gas   SCC code
          Unit   Consumption rate data   Method   C.L.
     Activity
          Autos
               Flow   Speed   Veh. mix
          Population
               Persons   Housing units   Hous. mix
Line
     (See Area--elements are essentially identical)
```

E. Format Extensions for Batch Data Entry

To prepare the data items off-line for batch entry, it is necessary to provide additional format conventions to indicate the logical boundaries of data components and the hierarchic level structure of each data item. If an existing data management system is obtained, it will have its own formats for this purpose.

If a data management system is expected to be used to maintain the RAPS Emission Inventory, but the scheduling of data processing requires that data be prepared for machine entry before the entry formats for that system are available, then this format can be used to enter the data onto machine-readable media, and the formats converted later to those required by the system. The special-purpose conversion program will be a temporary program used only once to process the data previously entered. After that, all new data will be prepared directly in the system format.

This extended format can also be used for the purpose of making sequential files for temporary use without the use or support of a hierarchic data management system. For this latter purpose, it is also useful to include a code to show whether a given data item is a current one in the file or has been replaced by an updated version, because the actual deletion of items and compaction of the file will require processing by a file maintenance program.

The characters chosen as delimiters for this extended format have not been used for the internal data formatting. These data structures, together with all format defining characters, can be implemented within the conventional 64-character ASCII subset that is available on most keyboard data entry devices and printers:

[n	Left bracket, followed by an integer, indicates opening of a hierarchic data level. n = data level
n]	Close data level n, and all inner levels.
< >	Delimiters of data element names
#	Pound sign - data element separator.

Each new data item will begin with [1. To indicate the status of the item, the integer 1 can be changed. [1 means that the item is a current one in the file; [0 means that it has been superseded. A partial example of a data item shows the manner of use of these format controls:

```
[1 <P> [2 <SI> # 234# MFG# UNIVERSAL HORSE-COLLARS# 999 WHINNY ST.,
ST. LOUIS, MO.# 70# 2] [2 <POLLUTANTS> # SO2 [3# G/S # M:1/1.4,
2/1.7, 3/1.9 ------ 12/1.3# 3] # HC [3# KG/HR # A:69-72/19.5# 2] [2
<STACK> # 1 [3# 321.0,963.1# 22# 0.83# 35# 300# 1]
```

The <P> denotes this as a point source (not needed unless all types of sources are included on one file). The denotation <SI> is the abbreviated name for Source Identifiers, a level 2 data structure. The denotation <POLLUTANTS> is the name of the next level 2 structure, but it contains two level 3 data sets. The terms SO2 and HC are not names of data structures, they are data, but a level 3 data structure depends from each of them. <STACK> is the name of another level 2 data component, containing the parameters of each stack.

F. Implementation

The next steps in the implementation of this emission inventory are the following:

- Specify the set of point sources, area sources, and line sources in the St. Louis metropolitan area that will be used as the initial basis for the RAPS emission inventory.

- Assemble the data applicable to these sources from other inventories and from other data sources.

- If a general-purpose data management system is not available, then write a system of programs for file definition, data entry, and updating of the emission inventory.

- Specify data entry procedures based jointly on the formats described in this report and the capabilities of the system. Any conflicts must be resolved by changing the format structures or the choice of punctuation characters, as necessary.

- Enter a small set of data to verify the correctness of the structure and the formats of the data base.

- Enter and proof-check the entire initial data set.

- Write and test the programs for
  - Computing emission values from consumption data;
  - Accessing data items on the basis of specified ranges of time, emission values, or source locations;
  - Constructing input data files for atmospheric models.

- Produce input data files for models using either data system procedures or separate computer programs.

G. Specifications for Computer Programs

1. Data Management System

These systems usually consist of a group of interconnected programs. This specification concerns only the external features related to the operation of the RAPS Emission Inventory.

- * Data bases of 20 million character size, containing up to 2000 items, each including 10 to 100 data elements, in up to 4 hierarchic levels.
- * Batch data entry from punch cards, magnetic tapes, or disk files.
- * Capability for defining hierarchic data structures, including list components.
- * Symbolic naming of data components.
- * Unrestricted lengths of lists and records.
- * Retrieval of items by content or partial content of any data component, including logical combinations of retrieval specifications.
- * Editing and updating individual items or groups of items.
- * Interface for external programs to access data items and data components in the files.
- * (Optional) Capability of calling special subroutines within the data system for operations requiring recognition of specialized formats within a data component.
- * (Optional) Construction of data files in specified formats for use by external programs.
- * (Optional) Sorting and indexing selected subfiles by content.

2. Input and Output Subroutines for Emission Model Programs

These are intended to be standardized subroutines, callable by any emission model program to provide access to the emission inventory file.

The input subroutine must:
  - Access source item via file address;
  - Read consumption data component from source item;
  - Extract SCC code, unit, time ranges, and consumption values;
  - Read emission factor for SCC code from Emission Factor File;
  - Convert values to the units required by the model.

The output subroutine must:
  - Generate calculated emission data element for the pollutant and for the time ranges defined by the model, in the format required by the inventory;
  - Append the emission element to the same source item from which the consumption data were read.

3. Verification Program

This can operate in three different ways. It can be part of a data entry program; it can be a separate program to correct preliminary data files prior to merging into the Master Inventory; or it can operate within the data management system on data sets retrieved by the system. It should perform these tasks:

- Verification of syntax of formatted data components for logically correct usage of operator and delimiter characters.
- Comparison of material names with those in a thesaurus file to verify that every name is one of an allowed set.
- Printing listings of erroneous items with bad elements marked.

4. Data File Generator Program

This capability may be included in a complete data management system. It should do the following operations as a minimum, although more extensive formatting capabilities may be useful.

- Accept user or file input of specifications for the exact sequence of data values and data representations required by an external program.
- Take its input from a subset of the emission inventory file selected by the data system and extract data from data components (the input subroutine for the emission model can be used for this purpose).
- Convert coordinate locations to the grid identification code used by the model.
- Interpolate emission values, if necessary, to the time intervals required by the model.
- Write the output file on the disk, magnetic tape, or punch cards, as specified.

DECEMBER 20th, 1974 SC553.T020CR
Revised

REGIONAL AIR POLLUTION STUDY

100% Completion Report for Task Order No. 20
Step II - Point Source Inventory

RAPS Emission Inventory Data Handling System

General Order No. 553

Contract No. 68-02-1081

Prepared For

ENVIRONMENTAL PROTECTION AGENCY

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1.0 Introduction

2.0 Input Format Overview

3.0 Emission Data Input and Update Formats

4.0 Retrieval Request Card Format

5.0 Financial

6.0 Appendices

- A. System 2000 Definition
- B. Component Name Dictionary
- C. Coding Sheet for Point Source Data

1.0 Introduction

This report contains the results of Rockwell's efforts in designing all system inputs to the RAPS Emission Inventory data handling system. The scope of these efforts has been limited to the point source data; the results have been carefully coordinated with NADB and Fred Littman and his efforts on RAPS tasks 16 and 17; these tasks constitute the total point source input at this time.

2.0 Input Format Overview

In coordination with Fred Littman and NADG, the input formats and content for the point source Emission Inventory is complete. The mechanism for data collection and recording in St. Louis indicated that input should be from fixed field cards. A coding form has been developed (Appendix C) to assist the data clerk in translating data from a number of different forms supplied by the point source plants or data gathering personnel.

Emission Inventory data is input as punched cards in one of the six formats specified herein. Data retrieval and reporting is controlled through two additional formats (card types 7 and 8). Provision will be made within the Emission Inventory Program for handling plant operating schedules and for the translation of annual data to hourly values by means of mathematical models to be supplied from the methodology studies.

The formats relate directly to the content and the structure within System 2000. Point Source data will be contained in a single file within the Emission Inventory. The System 2000 file definition for this data is attached as Appendix A; a component name dictionary is included as Appendix B.

Although the methodologies and contents for other than point source data have not been finalized, the retrieval keys are defined at this time.

Columns 78, 79 and 80 on each card are reserved for system and identification purposes. Column 78 contains an action code to indicate inclusion, update or deletion in the data base. The NEDS codes A, C, D for add, change or delete are the only acceptable entries. Column 79 contains an indicator of the data type.

2.0 (Continued)

P = Point Source Data

A = Area Source Data

L = Line Source Data

C = Complex Source Data

T = Total Emission

Column 80 contains the card number; acceptable entries are 1 - 8.

3.0 Emission Data Input and Update Formats

Contents for the Point Source Data contained in the RAPS Emission Inventory will be entered into the system in the format defined herein. Data will be prepared on cards for input to the editing program; the editing program will produce an edited tape containing card images for input into the data base. The system itself will have the option of selecting direct card input or input from a tape formatted into card images.

All contents of the point source inventory are contained in Card types 1 - 6. Card 1 contains plant identification information and is required when the user wishes to include or update this information. Card 2 contains the stack identification information. Similarly, card 2 is required for inclusion or update of the stack identification parameters. Card 3 contains information relevent to the control equipment installed on a particular stack. It is required for inclusion or change of this information. Card 4 contains source data and is required for identification for all inclusions. Card 5 contains actual data values to be included in the inventory. Card 6 contains comments and is optional. Once card types 1 - 3 are entered, they need not be repeated for every card types 4, 5, or 6 entry.

This revised report reflects changes made at the direction of NADB. Rockwell feels the input structure originally proposed represents a more viable design to accomplish the original and specific objectives of the RAPS inventory.

INPUT FORMAT FOR POINT SOURCE DATA

Card 1 - Plant Identification

Column	Field Size	Contents/Notes
1-2	2	STATE CODE - Integer (NEDS) 14 = Illinois 26 = Missouri
3-6	4	COUNTY CODE - Integer (NEDS)
7-10	4	PLANT ID - Integer (NEDS)
11-35	25	PLANT NAME - Alphanumeric
36-58	23	STREET ADDRESS - Alphanumeric
59-63	5	ZIP CODE - Integer
64-67	4	CITY CODE - Integer (NEDS)
68-71	4	SIC - Integer (NEDS)
72-76	5	SEQUENCE - Integer Arithmetically increasing numbering scheme allowing for up to 100,000 cards. Sequence numbers must be unique in a given update file.
77	1	OWNERSHIP CODE - Alphanumeric (NEDS) P = Private L = Local S = State F = Federal U = Utilities
78	1	ACTION CODE - Alphanumeric (NEDS) A = Add C = Change D = Delete
79	1	POINT SOURCE CODE (=P)
80	1	CARD TYPE (=1)

INPUT FORMAT FOR POINT SOURCE DATA

Card 2 - Stack Identification

Column	Field Size	Contents/Notes
1-2	2	STATE CODE - integer (NEDS) 14 = Illinois 26 = Missouri
3-6	4	COUNTY CODE - integer (NEDS)
7-10	4	PLANT ID - integer (NEDS)
11	1	MODELLERS FLAG - integer Usually is zero for regular use; contains a non-zero integer if a modeller has duplicated data for some time interval from a field study.
12-13	2	STACK ID - integer
14-15	2	UTM ZONE - integer The UTM zone code in which the stack resides.
16-21	6	HORIZONTAL UTM COORDINATE - decimal (in KM)
22-28	7	VERTICAL UTM COORDINATE - decimal (in KM)
30-33	4	AREA ID - integer (RTI gridding study)
45-48	4	TEMPERATURE OF STACK GAS - integer (^{o}F)
50-53	4	STACK HEIGHT - integer (feet)
55-58	4	BOCAP - boiler design capacity (10^6 BTU/hour)
60-64	5	STACK DIAMETER - decimal (feet)
67-71	7	FLOW RATE - integer (cfm)
72-76	5	SEQUENCE - integer Arithmetically increasing numbering scheme allowing for up to 100,000 cards. Sequence numbers must be unique in a given update file.
78	1	ACTION CODE - Alphanumeric (NEDS) A = Add C = Change D = Delete

Card 2 - (Continued)

Column	Field Size	Contents/Notes
79	1	POINT SOURCE CODE (=P)
80	1	CARD TYPE (=2)

INPUT FORMAT FOR POINT SOURCE DATA

Card 3 - Stack Control Equipment

Column	Field Size	Contents/Notes
1-2	2	STATE CODE - integer (NEDS) 14 = Illinois 26 = Missouri
3-6	4	COUNTY CODE - integer (NEDS)
7-10	4	PLANT ID - integer (NEDS)
11	1	MODELLERS FLAG - integer Usually is zero for regular use; contains a non-zero integer if modeller has duplicated data for some time interval from a field study.
12-13	2	STACK ID - integer
15-17	3	Primary control code for SO_2 - integer (NEDS)
18-20	3	Secondary control code for SO_2 - integer (NEDS)
21-24	4	Efficiency of SO_2 control (in percent)
26-28	3	Primary control code for CO - integer (NEDS)
29-31	3	Secondary control code for CO - integer (NEDS)
32-35	4	Efficiency of CO control (in percent)
37-39	3	Primary control code for NO_x - integer (NEDS)
40-42	3	Secondary control code for NO_x - integer (NEDS)
43-46	4	Efficiency of NO_x control (in percent)
48-50	3	Primary control code for HC - integer (NEDS)
51-53	3	Secondary control code for HC - integer (NEDS)
54-57	4	Efficiency of HC control (in percent)
59-61	3	Primary control code for particulates - integer (NEDS)

Card 3 - (Continued)

Column	Field Size	Contents/Notes
62-64	3	Secondary control code for particulates - integer (NEDS)
65-68	4	Efficiency of particulate control (in percent)
70-71	2	YEAR OF RECORD - integer
72-76	5	SEQUENCE - Integer Arithmetically increasing numbering scheme allowing for up to 100,000 cards. Sequence numbers must be unique in a given update file.
78	1	ACTION CODE - Alphanumeric (NEDS) A = Add C = Change D = Delete
79	1	POINT SOURCE CODE (=P)
80	1	CARD TYPE (=3)

INPUT FORMAT FOR POINT SOURCE DATA

Card 4 - Source Data

Column	Field Size	Contents/Notes
1-2	2	STATE CODE - integer (NEDS) 14 = Illinois 26 = Missouri
3-6	4	COUNTY CODE - integer (NEDS)
7-10	4	PLANT ID - integer (NEDS)
11	1	MODELLERS CODE - integer Usually is zero for regular use; contains a non-zero entry if a modeller has duplicated data for some time interval from a field study.
12-13	2	STACK ID - integer
14-15	2	POINT ID - integer Identifies a particular process that vents through the stack (col. 12-13).
16-21	6	FUEL HEAT CONTENT - decimal In units of 10^6 BTU/SCC; i.e., per units used in the SCC number.
22-25	4	SULFUR IN FUEL - per cent
26-29	4	ASH IN FUEL - per cent
31	1	ESTIMATION METHOD - integer (NEDS) 1 - Emission Measurement 2 - Material Balance 3 - Emission Factor (AP-42) 4 - Guess 5 - Special Emission Factor
33-35	3	POLLUTANT - Alphanumeric Right justified: SO_2, CO, NOX, HC, PAR. Plus Trace Elements: AS, AB, BA, BE, B, CD, CR, CU, PB, MG, MN, HG, MO, NI, P, SE, AG, TI, V, ZN, POM, and HEM.

INPUT FORMAT FOR POINT SOURCE DATA

Card 4 - Source Data (Continued)

Column	Field Size	Contents/Notes
37-40	4	UNITS - Alphanumeric Right justified: OZ - Ounces LB- Pounds LBS - Pounds of Steam TON - Tons GAL - 10^3 Gallons CUFT - 10^6 Cubic Feet CFT - 10^3 Cubic Feet KW - Kilowatts MW - Megawatts BBL - Barrels (10^3 barrels @ 42 gal/bbl) BALE - Bales CUYD - Cubic Yards PPM - Parts per million PCNT - Per Cent (PPM and PCNT are special cases to be discussed in cards 5 - type 2)
41	1	TIME INCREMENT - Alphanumeric A - Annual M - Month W - Week D - Day S - Shift H - Hour This field is used in conjunction with UNITS to yield a rate in the form UNITS/TIME INCREMENT: e.g., hourly data of coal burned would be tons per hour.
43-47	5	START DATE - integer A five digit representation of the date composed of the last two digits of the year followed by the Julian date. Of the form YYDDD.
49-50	2	START HOUR - integer A two digit representation of the hour on which the data (card 5) starts. A twenty-four hour system ranging 00-23 where hour 23 is 11-12 PM.

INPUT FORMAT FOR POINT SOURCE DATA

Card 4 - Source Data (Continued)

Column	Field Size	Contents/Notes
52-56	5	STOP DATE - integer Similar to the START DATE but is the inclusive stop date.
58-59	2	STOP HOUR - integer Similar to the start hour but is the inclusive stop hour.
61-63	3	THERMAL EFFICIENCY - per cent The thermal efficiency of a boiler is used specifically for power generation emission calculations. Otherwise leave blank.
64-71	8	SCC NUMBER - integer (NEDS)
72-76	5	SEQUENCE - integer Arithmetically increasing numbering scheme allowing for up to 100,000 cards. Sequence numbers must be unique in a given update file.
78	1	ACTION CODE - Alphanumeric A = Add C = Change D = Delete
79	1	POINT SOURCE CODE (=P)
80	1	CARD TYPE (=4)

INPUT FORMAT FOR POINT SOURCE DATA

Card 5 - Hourly Process Data (Type 1)

Column	Field Size	Contents/Notes
1-2	2	STATE CODE - integer (NEDS) 14 = Illinois 26 = Missouri
3-6	4	COUNTY CODE - integer (NEDS)
7-10	4	PLANT ID - integer (NEDS)
11	1	MODELLERS FLAG - integer Usually left blank for regular use; contains a non-zero entry if a modeller has duplicated data for some time interval from a field study.
12-13	2	STACK ID - integer
14-15	2	POINT ID - integer Identifies a particular process that vents through the stack (columns 12-13).
16-71	7 each	DATA - 8 data fields per card The first two columns in each data field are used to indicate how many consecutive repetitions occur for the following five columns containing actual data values. If for an eight hour shift, the data is constant per hour; an 8 in the first two columns followed by the data in the next five columns is the same as a 1 in the first two columns and the data in the next five columns repeated eight times. If blank the repetition count is assumed to be 1.
72-76	5	SEQUENCE - integer Arithmetically increasing numbering scheme allowing for up to 100,000 cards. Sequence numbers must be unique in a given update file.
77	1	TYPE OF CARD 5 - integer (=1)
78	1	ACTION CODE - Alphanumeric (NEDS) A = Add C = Change D = Delete
79	1	POINT SOURCE CODE (=P)
80	1	CARD TYPE (=5)

INPUT FORMAT FOR POINT SOURCE DATA

Card 5 - Hourly Emission Data (Type 2)

Column	Field Size	Contents/Notes
1-2	2	STATE CODE - integer (NEDS) 14 = Illinois 26 = Missouri
3-6	4	COUNTY CODE - integer (NEDS)
7-10	4	PLANT ID - integer (NEDS)
11	1	MODELLERS FLAG - integer Usually is a zero for regular use; contains a non-zero entry if a modeller has duplicated data for some time interval from a field study.
12-13	2	STACK ID - integer
14-15	2	POINT ID - integer Identifies a particular process that vents through the stack (columns 12-13).
16-71	7 each	DATA - 8 data fields per card The first two columns in each data field are used to indicate how many consecutive repetitions occur for the following five columns containing actual data values. If for an eight hour shift, the data is constant per hour an 8 in the first two columns followed by the data in the next five columns is the same as a 1 in the first two columns and the data in the next five columns repeated eight times. If blank the repetition count is assumed to be 1. Card 5 Type 2 (indicated in column 77) uses two parameters for stack monitoring, first the ppm or per cent value immediately followed by the exit gas flow rate in units of 10^3 (always coded in piggyback fashion in this order). The repetition count is still optional but differs from Type 1 in that it need only be coded for the first of the piggyback values.
72-76	5	SEQUENCE - integer Arithmetically increasing numbering scheme allowing for up to 100,000 cards. Sequence numbers must be unique in a given update file.

INPUT FORMAT FOR POINT SOURCE DATA

Card 5 - Hourly Emission Data (Type 2) (Continued)

Column	Field Size	Contents/Notes
77	1	TYPE OF CARD 5 - integer (=2)
78	1	ACTION CODE - Alphanumeric (NEDS) A = Add C = Change D = Delete
79	1	POINT SOURCE CODE (=P)
80	1	CARD TYPE (=5)

INPUT FORMAT FOR POINT SOURCE DATA

Card 5 - Annual Pattern/Data (Type 3)

Column	Field Size	Contents/Notes
1-2	2	STATE CODE - integer (NEDS) 14 = Illinois 26 = Missouri
3-6	4	COUNTY CODE - integer (NEDS)
7-10	4	PLANT ID - integer (NEDS)
11	1	MODELLERS FLAG - integer Usually left blank for regular use; contains a non-zero entry if a modeller has duplicated data for some time interval from a field study.
12-13	2	STACK ID - integer
14-15	2	POINT ID - integer Identifies a particular process that vents through the stack (columns 12-13).
16-20	6	DATA - integer Actual data value for the year.
22-71	50	FREE FIELD OPERATING PATTERN See following pages for discussion.
72-76	5	SEQUENCE - integer Arithmetically increasing numbering scheme allowing for up to 100,000 cards. Sequence numbers must be unique in a given update file.
77	1	TYPE OF CARD 5 - integer (=3)
78	1	ACTION CODE - Alphanumeric (NEDS) A = Add C = Change D = Delete
79	1	POINT SOURCE CODE (=P)
80	1	CARD TYPE (=5)

Card 5 Type 3 - Operating Patterns

Character	Description
W	Indicates a weekly pattern by days. (1 = Mon,...7 = Sun); 1-5 = 1,2,3,4,5 = Mon. through Fri.
D	Indicates actual operating days in Julian form inclusively. (1 = Jan. 1,...365 = Dec. 31). Thus 1-181 is the first six months of a non-leap year.
H	Indicates an actual (counted) operating hour. (0 = 12 A.M. - 1 A.M.,...23 = 11 P.M. - 12 Midnight. Thus, 08-16 is from 8 A.M. through 5 P.M.
:	Means data follows.
,	Is a simple data-set separator.
-	Is an inclusive connector (first through last).
C	Is the continuation character if more than one card is needed. It must follow a comma.
blank	Indicates end of code.

EXAMPLES

(1) D:1-365,W:1-7,H:00-23

(2) D:2-358,360-365,W:1-7,H:8-16

(3) D:1-151,166-365,W:1-5,H:8-16

(4) D:1-365,W:1-5,H:7-15,W:6,H:10-13

(5) D:2-48,50-184,186-244,246-331,333-358,360-365,C
W:1-5,H:8-17

Operating Patterns

In order to calculate an hourly emission rate from a source that provides only annual data, one needs to know not only the number of hours over which the data are representative but also which particular hours. A system of recording operating patterns was thus devised to accomodate the handling of such patterns. The concept of specific typical patterns was discarded as it became apparent that the atypical was more typical than "typical." Originally the system was designed to account for emission variations by means of a weighting coefficient but this proved unsatisfactory in two ways. First, it was extremely difficult to code the weighting scheme so that it would total to the original annual number and second, a system without weighting coefficients would still be in the allowable range for error as defined by the sensitivity analysis discussed in RAPS T.O. 16.

The following page contains the definition of the character set and some sample operating patterns. A brief explanation of these should enable the reader to code any possible operating schedule.

Example 1 - This operating pattern indicates that the particular SCC code - defined process - is operated every (365) day of the year, every day of the week (Mon-Sun), and every hour of the day. This example illustrates a continuous process whose hourly emission rate is equal to its annual rate divided by 8760.

Example 2 - This example depicts a process operating from 8am to 5pm everyday of the year except Christmas and New Years. The annual rate divided by (363 days x 9 hours) yields the hourly rate for the hours this process is in operation.

Operating Patterns

Example 3 - Assume a plant has a process that operates from 8 to 5 everyday except weekends and closes the first two weeks in June for vacation. Example 3 defines this schedule for a non-Leap Year resulting in the hourly rate of the annual rate divided by 2250.

Example 4 - This pattern represents a process operating from 7 to 4 Monday through Friday and from 10 till 2 on Saturday afternoons. The annual rate divided by 3858 is the hourly rate for the scheduled hours of operation.

Example 5 - This example illustrates the use of the continuation character (C). This process is in operation from 8 to 6, Monday through Friday except for the six legal holidays listed (in order). New Year's Day, Washington's birthday, Independence Day, Labor Day, Thanksgiving Day, and Christmas. If the annual emission rate is divided by 2570 the quotient will indicate the hourly emission rate for a schedule thus defined.

INPUT FORMAT FOR POINT SOURCE DATA

Card 6 - Comments

Column	Field Size	Contents/Notes
1-2	2	STATE CODE - Integer (NEDS) 14 = Illinois 26 = Missouri
3-6	4	COUNTY CODE - Integer (NEDS)
7-10	4	PLANT ID - Integer (NEDS)
11	1	MODELLERS FLAG - Integer Usually left blank for regular use; contains a non-zero entry if a modeller has duplicated for some time interval from a field study.
12-13	2	STACK ID - Integer
14-15	2	POINT ID - Integer Identifies a particular process that vents through the stack (columns 12-13).
16-71	56	COMMENTS - Alphanumeric Notes regarding unusual conditions or circumstances that reflect the quality of data. Specific to SCC - Process ID and may repeat with each Card 4. Should be used sparingly so as not to waste computer space.
72-76	5	SEQUENCE - Integer Arithmetically increasing numbering scheme allowing for up to 100,000 cards. Sequence numbers must be unique in a given update file.
78	1	ACTION CODE - Alphanumeric (NEDS) A = Add C = Change D = Delete
79	1	POINT SOURCE CODE (=P)
80	1	CARD TYPE (=6)

4.0 Retrieval Request Card Format

Card types 7 and 8 contains information to the system for data retrieval. The first card is a fixed format with a field for each of the retrieval options. The options include all of those available for NEDS data; also available are selection parameters to describe the type of units, the time interval and increment of data (hourly, daily, etc.) required by the modeller or other user.

The presence of an entry in a specified field indicates selection of only those contents of the data base specified; all possible entries for a field which exists in the data base are selected by leaving the field blank.

The user includes card type 8 to describe to the system the form and ordering of a requested subset of the data base. This card is used in conjunction with card type 7 to describe a retrieval. The user describes the data tape or report requested by inclusion of this fixed format card. The modeller will be expected to extract the particular fields of interest from the data base retrieved. The types of reports are mentioned here but are completely defined in the Retrieval Design report. Ordering of the subset of the data base will be by any retrieval key capable of being sequenced.

INPUT FORMAT FOR POINT SOURCE DATA

Card 7 - Retrieval

Column	Field Size	Contents/Notes
1-2	2	STATE - Integer (NEDS) 14 = Illinois 26 = Missouri
3-4	2	UTM ZONE - Integer (NEDS)
5-8	4	COUNTY - Integer (NEDS)
9-12	4	CITY - Integer (NEDS)
13-17	4	AREA ID - Integer
18-21	4	PLANT ID - Integer (NEDS)
22	4	MODELLERS FLAG - Integer Usually is zero for regular use; contains a non-zero entry if a modeller has duplicated data for some time interval from a field study.
23-24	2	STACK ID - Integer
25-26	2	POINT ID - Integer
27-29	3	POLLUTANT - Alphanumeric
30	1	OWNERSHIP - Alphanumeric P = Private L = Local S = State F - Federal U = Utilities
31	1	TIME INCREMENT - Alphanumeric Indicates the granularity of data desired. A "D" would yield daily data between the start and stop dates. A = Annually M = Monthly W = Weekly D = Daily H = Hourly

INPUT FORMAT FOR POINT SOURCE DATA

Card 7 - Retrieval - (Continued)

Column	Field Size	Contents/Notes
32-36	5	START DATE - Integer A five digit representation of the date composed of the last two digits of the year followed by the Julian day. Of the form YYDDD.
37-38	2	START HOUR - Integer A two digit representation of the hour on which the data (card 5) starts. A twenty-four hour system ranging 00-23 where hour 23 is 11-12 Midnight.
39-43	5	STOP DATE - Integer Similar to the START DATE but is the inclusive stop date.
44-45	2	STOP HOUR - Integer Similar to the start hour but is the inclusive stop hour.
46	1	SCCI - Integer
47-48	2	SCCII - Integer
49-52	3	SCCIII - Integer
53-54	2	SCCIV - Integer
72-76	5	SEQUENCE - Integer Arithmetically increasing numbering scheme allowing for up to 100,000 cards. Sequence numbers must be uinque in a given update file.
78	1	P = POINT
80	1	CARD = 7

Card 8 - Retrieval

Columns	Field Size	Field Contents
1-4	4	Report Type
6-8	3	Data File Media
10-69	5/entry	Ordering option list
71	1	UNITS DESIRED - Alphanumeric M = Metric S = Standard
72-76	5	SEQUENCE - integer Arithmetically increasing numbering scheme allowing for up to 100,000 cards. Sequence numbers must be unique in a given update file.
79	-	
80	1	CARD NUMBER (=8)

Acceptable entries for each field:

Report Type

PSL	Point Source Listing
PSLC	Point Source Listing Condensed
SUMP	Point Source Summary Listing
ASL	Area Source Listing
ASLC	Area Source Listing Condensed
SUMA	Area Source Summary
MDLT	Modellers Tape
DUMP	Data Base Dump

Card 8 - Retrieval - (Continued)

All area report formats may be used for line, complex, area and total emission estimates.

Data File Media:

MT	Mag Tape
DK	Disk
DR	Drum
HS	High Speed Printer
(Other)	To be defined

ORDERING OPTION LIST:

Acceptable entries in each field:

Entry	Explanation
STATE	Order by state code
CNTY	Order by county ID
IDPT	Order numerically by point ID
IDAR	Order numerically by area ID
SCC1	Order numerically by SCC code field I
SCC2	Order numerically by SCC code field II
SCC3	Order numerically by SCC code field III
SCC4	Order numerically by SCC code field IV
SCC	Order numerically by SCC code
TIME	

SC553.T020CR March 5, 1975

REGIONAL AIR POLLUTION STUDY

100% Completion Report for Task Order No. 20
Step III - Retrieval Design

RAPS Emission Inventory Data Handling System

General Order No. 553

Contract No. 68-02-1081

Prepared For

ENVIRONMENTAL PROTECTION AGENCY

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by

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368<

STEP III

Retrieval Design

1.0 Introduction
2.0 Summary Formats
3.0 Modeling Tape Formats
4.0 Retrieval Keys

1.0 Introduction

This report details the results of Rockwell's efforts in design of retrieval formats for the RAPS Emission Inventory. Summary reports similar to those commonly used in NEDS have been formatted with provision for hourly or other time interval data in tabular form. For consistency, data for input to the modeling program will be formatted in a manner similar to the input formats; the modeler will select the fields of interest. Retrieval may be made on any element of the data base which was defined as key (in Step IV report), by a user accessing the data base directly through System 2000. The retrieval keys available to the user through the RAPS Emission Inventory Data Handling System were initially defined in the Step II report and will be detailed in Section 4.

2.0 Summary Formats

Four formatted summaries will be available to the user through the RAPS Emission Inventory Data Handling System:

1. A complete Point Source Listing
2. A Condensed Point Source Listing
3. A Daily Summary
4. A complete data base dump selectable by plant or area.

2.1 Point Source Listing

An example of the format for the RAPS Emission Inventory Point Source Listing appears as Figure 1. Tabulation of the data continues for as many pages as required. For a given plant, the descriptive information appears on the first page only; the main heading reflecting data and page number and the column headings are repeated on each page. Data may be tabulated for any of the time intervals allowed as retrieval keys.

2.2 Condensed Point Source Listing

A sample of the format for the Condensed Point Source Listing appears as Figure 2. As for the Point Source Listing, all time interval data is in tabular form with descriptive information on the first page only; date and page identifier and column headings appear on each page.

FIGURE I

```
MO/DD/YY                  R A P S  S T.  L O U I S  E M I S S I O N  I N V E N T O R Y                  PAGE 999

                                   P O I N T  S O U R C E  L I S T I N G


              NAME:     ILL. POWER COMPANY                                  PLANT ID:  0001
              ADDRESS: WOOD RVR STA EAST ALTON 92024                        POINT ID:  01
              CITY(000): UNKNOWN                                            AQCR(70):  METROPOLITAN ST. LOUIS
              COUNTY(4680): MADISON CO                                      SIC(4911): ELECTRIC SERVICES
              STATE(14): ILLINOIS                                           OWNERSHIP: UNKNOWN

              SCC(1-01-002-02): EXTCOMB    -ELECTRIC GENERATN-BITUMINOUS COAL   ->100MMBTU PULVDRY

          UTM GRID COORDINATES  STACK PARAMETERS                  EMISSION FACTORS      FUEL CONTENT
          ********************  ****************                  *****************     ************

          UTM ZONE:  0015       STACK HEIGHT:          0250 FT    SO2:    AP-42         SULFUR: 2.90%
          HORIZONTAL: 748.70 KM STACK DIAMETER:        015.5 FT   CO:     AP-42         ASH:    10.6%
          VERTICAL:  4305.40 KM GAS TEMPERATURE:       0329° F    NOX:    AP-42         HEAT:   22 MBTU/TON
                                GAS FLOW RATE:         0154649 SCFM HC:   AP-42
                                PLUME HT(NO STACK):    0000       PART:   AP-42

                                              CONTROL EQUIPMENT
                                              *****************

    POLLUTANT:     ***** SO2 *****     ***** CO *****    ***** NOX *****    ***** HC *****   **** PARTICULATE ****
    PRIMARY:       NONE                NONE              NONE               NONE             GRAVITY COLLECTOR
    SECONDARY:     NONE                NONE              NONE               NONE             NONE
    EFFICIENCIES:  00.0%               00.0%             00.0%              00.0%            15.0%


                         **************************************************

                                        COMPUTER CALCULATED EMISSIONS


    DATE        HOUR            SO2             CO             NOX              HC               PART
  ********      ****       ***********     **********     ***********      ***********      ***********

  10/03/74       01           104.0 KG         8.5 KG

  10/03/74       02           105.7 KG         8.1 KG

  10/03/74       03           106.4 KG         7.7 KG        35.0 KG

     .            .               .              .               .

     .            .               .              .               .

     .            .               .              .               .
```

FIGURE

```
MM/DD/YY              R A P S  S T.  L O U I S  E M I S S I O N  I N V E N T O R Y                    PAGE 999

                               CONDENSED POINT SOURCE LISTING FOR PARTICULATE
                                  FOR ALL VALUES > THAN OR = TO     0
                                  EMISSIONS ARE IN KILOGRAMS PER HOUR

                                  * * * * * * * * * * * * * * * * * *


                         0001: ILL. POWER COMPANY              POINT: 01
                               WOOD RVR STA EAST ALTON 92026   OWNERSHIP:UNKNOWN
                         4680: MADISON                         SIC: 4911
                           14: ILLINOIS                        SCC: 1-01-002-02
                          070: METROPOLITAN ST. LOUIS
                          123: GRAVITY COLLECTOR               EFF= 15 %



                                  * * * *  EMISSIONS IN KG  * * * *


  DATE      HOUR          SO2             CO            NOX            HC            PART
********    ****     ***********     **********     **********     **********     **********

10/03/74     01         104.0            8.5            7.3            2.0

10/03/74     02         105.7            8.1            6.9            2.2

10/03/74     03         106.2            7.8            6.5            2.3             .2
```

373<

2.3 Point Source Daily Summary

An example of a daily summary is included as Figure 3. Daily totals for the five pollutants of interest are tabulated by SCC sub-fields I, II and III. All categories relative to the St. Louis inventories will be included in the summary.

2.4 Data Base Dump*

To ensure data base integrity or allow correction of misplaced data, the List Command in the Immediate Access mode may be invoked to produce an indented listing of data base contents selectable by level 0 entry in the data base. (A level 0 entry for Point Source is a Plant) This listing should allow detection of incorrect insertions into the data base, and enable deletion and reinsertion of the entries.

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* The dump feature necessitates inclusion of the Report Type DUMP as an acceptable entry on Card 8, columns 1-4.

FIGURE III

```
MM/DD/YY              R A P S  S T.  L O U I S  E M I S S I O N  I N V E N T O R Y              PAGE  1
                            P O I N T  S O U R C E  D A I L Y  S U M M A R Y
                                       FOR AQCR 070 ON MM/DD/YY


                          PARTICULATES      SO2          NOX           HC           CO
                          ************  ************  ************  ************  ************
FUEL COMBUSTION              KG/DAY        KG/DAY        KG/DAY        KG/DAY        KG/DAY
***************

  EXTERNAL COMBUSTION

    ELECTRIC GENERATION

      BITUMINOUS COAL       ________      ________      ________      ________      ________
      RESIDUAL OIL          ________      ________      ________      ________      ________
      DISTILLATE OIL        ________      ________      ________      ________      ________
      NATURAL GAS           ________      ________      ________      ________      ________
      TOTAL (ELEC GEN)      ________      ________      ________      ________      ________

    INDUSTRIAL FUEL

      BITUMINOUS COAL       ________      ________      ________      ________      ________
      RESIDUAL OIL          ________      ________      ________      ________      ________
      DISTILLATE OIL        ________      ________      ________      ________      ________
      NATURAL GAS           ________      ________      ________      ________      ________
      PROCESS GAS           ________      ________      ________      ________      ________
      WOOD                  ________      ________      ________      ________      ________
      LIQUID PETROL GAS     ________      ________      ________      ________      ________
      TOTAL (INDUSTRIAL)    ________      ________      ________      ________      ________

    COMM-INSTITUTIONAL FUEL

      BITUMINOUS COAL                   — E T C —
      RESIDUAL OIL
      DISTILLATE OIL
      NATURAL GAS
      LPG
      TOTAL (COM-INST)
```

375<

3.0 Modeling Tape Formats

Upon request from the user ** a tape containing the requested subset of the data base will be produced; the tape will contain the data in card image format. Should the requested time interval for the data differ from that stored in the data base, the appropriate model will be applied and the requested time interval data will be calculated.

Only the data card format will differ from the input formats (see Step II Report); cards 1-4 will contain the same information as on input but with columns 72-80 left blank. To avoid redundancy in the data descriptors for card type 5, all 80 columns of the card image will be utilized; data will be present in 16 fields of width 5. The start and stop times determine the quantity of data present in the card type 5 images.

** An additional acceptable entry must be included under card 8 (retrieval formats). The letters MDLT will indicate that the Report Type for retrieval will be a modeler's tape.

4.0 Retrieval Keys

Retrieval may be made directly on any element of the data base defined as key. (See Appendix A, Step II Report; or, Step IV Report, Section 4)

Card type 7 contains fields for each of the RAPS Emission Inventory Data Handling System retrieval keys. These keys include those available through NEDS. Retrieval is made by inserting the acceptable entry on which the data is to be selected in the appropriate field as defined in Step II. The following are the component keys for retrieval under the data handling system.

1. State
2. UTM Zone
3. County
4. City
5. Area ID
6. Plant ID
7. Stack ID
8. Point ID
9. Pollutant
10. Ownership
11. Time
12. SCC Code Fields

Information Transfer

Information transfer may be subdivided into technology transfer--publication, implementation, and use of the emission inventory techniques developed in RAPS, and data transfer--the dissemination of RAPS emission inventory data for use by others.

Involved with the matter of data use and transfer is the problem of data confidentiality. It will be necessary for the data handling system to maintain confidentiality of data actually found to be confidential, and the point sources/state-local control agencies must agree as to what date actually must be maintained under security procedures.

Because of the very nature of this aspect of the RAPS study, considerations of both technology and data transfer will be undertaken in the later stages of the project, probably in FY'76.